INTRODUCTION TO 3-D

INTRODUCTION TO 3-D

THREE DIMENSIONAL PHOTOGRAPHY IN MOTION PICTURES

With Chapters on Wide-screen, CinemaScope, Cinerama and Stereo Television

by

H. DEWHURST
A.R.C.S., D.I.C.

THE MACMILLAN COMPANY
NEW YORK
1954

First published in the U.S.A., 1954

Printed in Great Britain by THE WHITEFRIARS PRESS LTD.
London and Tonbridge

PREFACE

THIS BOOK, as its title indicates, is intended to be only an introduction to 3-D for all who are interested: professional, amateur or just plain layman. It pretends to be nothing more than a mere survey but maybe, nevertheless, a comprehensive one; taking the whole wood for its purview, without concentrating too often or for too long on any particular tree. As such, it is hoped that this 'Introduction' will, despite this restriction, prove an adequate one; in that it is believed to rest on sound premises, information and orthodox reasoning and should therefore serve as a basis upon which, if so desired, the later supplementary reading of learned society papers and the like that it may have stimulated, could subsequently erect the edifice of a complete and thorough understanding of the theory and practice of stereoscopic photography and projection. In pursuance of this aim and that it may perhaps have a wider appeal, the book has been kept to all intents and purposes free from mathematical treatments and, where possible, even symbols; with the exception of a short derivation of the essential basic formulæ of geometrical projection, using the almost obvious-at-sight proof-methods of 'similar triangles', and even so, restricted to investigation in one plane only.

If one tree compared with the rest should prove to have been given more attention than its due share, it is pleaded in extenuation that a beam-splitting method employing only one film has been a laboratory preoccupation of the writer for many years and he is perhaps unconsciously biased in its favour for some applications, although naturally trying in this book to be impartial. The lapse, perhaps, can at least be excused on the grounds that there are few if any published treatments in any detail of beam-splitting methods in general and the present one may therefore prove useful if not enlightening. It may be too, that the arguments in favour of the retention of a fixed camera-lens interaxial-distance equal to the normal 'interocular' eye-spacing are stressed too much. If this be so, indulgence must again be asked as the writer has apparently come to be looked

upon as a protagonist if not a pioneer in regarding this particular ingredient as being an essential one, if ' Natural ' Vision is to be achieved; without, however, his having had the facilities and hence the problem to solve of large-scale screen projection to damp his theoretical ardour. In this connection a very recent paper,[11] prepared for the Motion Picture Research Council, Hollywood by Armin J. Hill is illuminating if not reassuring, recommending as it does the use of a relatively but not absolutely fixed interaxial spacing which is related to the focal length of the lens; instead of the widely varied interaxial, commonly adopted hitherto of late in other systems, which are related to the distance away of the photographed scene.

The text of the present book derives in considerable part from that which has appeared in a series of articles in the *Bolex Reporter*, the House magazine of Paillard Products Incorporated of New York by whom, through the courtesy of the Editor, Thomas H. Elwell, permission has been generously given to use freely this material of which they hold the copyright. Such portions of the text as these have been revised or rewritten, and supplemented where necessary by new material, to bring them up to date.

Great attention has been given to the two new opening chapters in which an unhurried and, it is hoped, exhaustive treatment has been attempted of the basic principles, especially those of a geometrical nature, that underlie a true application of *depth* in real life and in the projected reconstruction.

A chapter has been added dealing with the modern trends in Commercial Stereoscopic Projection, including the non-Stereoscopic ' 3-D ' competitors: Wide-Screen, CinemaScope and Cinerama. The book concludes with an appreciation of the chances of a system of Stereoscopic Television appearing in the near future which shall yet be compatible with normal two-dimensional viewing.

ACKNOWLEDGMENTS

The kindness and courtesy of the following in permitting the reproduction of, and in supplying material for, the illustrations is gratefully acknowledged: Paillard Products Incor-

porated, New York, U.S.A. ; Carl Bausch, U.S.A. ; John A. Norling, U.S.A.; Major Bernier, U.S.A.; L. P. Dudley, U.K.

The book is published by permission of the Ministry of Supply. The illustrations, so marked, are Crown Copyright and are reproduced by permission of the Controller, H.M. Stationery Office.

Finally, indebtedness for invaluable assistance is expressed to : Miss I. L. Smith for assistance with the text; Miss V. M. Francis for preparing the line diagrams and air-brush drawings; and to W. M. Hardy for many of the photographs.

H. D.

Radar Research Establishment,
Malvern.

November, 1953.

CONTENTS

LIST OF ILLUSTRATIONS

INTRODUCTION

WHAT is new about 'three-dimensions', or '3-D' as we have recently learnt to call it, is that a third dimension could be added to our existing 'two-dimensional' Motion Pictures whenever we wanted it, and whether we wanted it or not. What is old about 3-D or *stereoscopy*, to give it its older and more comprehensive name, is indeed ancient. We have most of us at one time or another had dealings with 'Euclid', but how many of us knew that its author, some 2,000 years or more ago, was cognisant of the crucial bearing that 'parallax' had on the perception of depth in human vision. Recent quincentenary celebrations too have reminded us that Leonardo da Vinci, in his versatile omniscience in the representational arts, in science and in anatomy, was aware of the dissimilarity in the pictures seen by the two eyes and may indeed have hit upon the possibility of imitating the perception of depth from this cause in nature by the construction of two slightly different drawings. It remained, however, for Charles Wheatstone, a century ago, scientifically to clarify the binocular basis upon which stereoscopic vision was truly founded; and it is indeed astonishing now to read, immediately prior to his researches and his revealing paper read before the Royal Society, how far from the mark were the prevailing theories of the time which had up to then and to everyone's satisfaction accounted for the perception of depth in Vision.

Wheatstone proved and illustrated his theory of binocular vision by the construction of stereoscopic pairs of drawings which, when viewed in his invention of the first optical stereoscope, took on the semblance of solidity. Wheatstone, a little later took advantage of the invention of Calotype photography by Fox Talbot to substitute photographs for drawings; a step in which he was closely followed by David Brewster, using the Daguerrotype process. Brewster had, in the meantime, invented another more practical and popular form of stereoscope in which

the stereoscopic pair was seen and merged direct by the interocularly separated halves of a convex lens.

During the latter half of the nineteenth century, the stereoscope had a tremendous vogue and a Victorian home was scarcely regarded as complete without one. In America, too, few parlours dispensed with a particularly popular modification of the Brewster stereoscope invented by Oliver Wendell Holmes. By the turn of the century, however, interest in the stereoscope as such had largely waned but the development and provision of stereoscopic photographing and viewing apparatus for amateurs, particularly on the Continent and in America, kept interest alive. In this sphere the Verascope camera of the French firm of Jules Richard and the Heidoscope/Rolleidoscope cameras produced by Franke and Heidecke in Germany were outstanding in the early decades of this century. In the period between the two wars a stereoscopic attachment for the Leica camera appeared, to be followed in the United States by a somewhat similar device, the 'Stereo-Tach', for adaptation to any camera of the miniature type.

It was during this period, some thirty years after Friese-Greene had first projected and viewed stereoscopic Motion Pictures in 1893, that the first commercial 3-D pictures were seen under the name of 'Plastigrams', using red and green 'anaglyph' spectacles as a viewing aid; to be followed eleven years later by the 'Audioscopik' films with sound effects, released by Metro-Goldwyn-Mayer. It is somewhat remarkable that after a further three-dimensionless eighteen years, some of these films should have been resuscitated under the name of 'Metroscopix' and seen again in the 3-D rush to meet the challenge of Television in 1953.

In the following pages, the story of stereoscopic projection is amplified and continued whilst discussing the basic principles and the methods of using them that have come to fruition at last on the commercial screen. In developing the march of events and discoveries in the progress of stereoscopic projection, the narrative is of necessity largely concerned with the work of pioneer inventors and investigators—the whole story to a large extent being exclusively confined to their efforts up to a short while ago. In rounding off the story, a chapter has been devoted

to a sketch of the subsequent trends of recent commercial development. A final chapter has been added to include a survey of the possible lines upon which the parallel development of Television 3-D might be expected; ending on a note of restraint in expecting the emergence for a considerable time of a 3-D system, compatible with simultaneous two-dimensional T.V. viewing, which could be considered as comparable in its prospects with those of Motion Picture 3-D.

CHAPTER I

THE FACTORS OF STEREOSCOPIC VISION

WHEN we look at something, let us say a landscape for example, what exactly is it that happens; what is the mechanism of ' looking '; what do we mean when we say we see an object; and what is it that adds up to that particular awareness of material objects, exterior to ourselves, that is summed up in the word Vision?

VISION AND THE HUMAN EYE

The extraordinary thing is that, although we may direct our eyes to some particular object as in our landscape example, and become aware of it by visual means, we do not in fact ' see ' it in the normally accepted sense of the word. What we are really doing is mentally examining an optical image formed on the back of the eye which is inverted upside-down and reversed left-and-right. How then is this image formed, and why are we so conscious of an apparent act of seeing?

The Retina

Reverting to the landscape, every object within it and every detail upon its surface is ' lit ', during normal daylight for example, by an infinitude of light rays emanating from the sun, either falling upon it directly or indirectly after reflection or scattering by the clouds, the atmosphere or other objects and details which constitute the rest of the immediate landscape. These rays, impinging on the object and its details, are absorbed in part and reflected in part. A red flower absorbs the blue rays from the white light incident upon it and reflects the remaining red rays more or less indiscriminately in all directions. Wherever we may stand, our eyes are receptive of some particular

bunch of reflected rays from the flower. These rays pass into the eyes and are collected and bent by the refractive ' crystalline ' lens behind the pupil of the eye on to the rear concave interior wall of the spherical eyeball where resides a network of up-ended nerve ends collectively called the *retina*. The eye is thus, except for its approximately spherical shape and a particular feature of the lens to be mentioned later, rather like the familiar box camera in which, as we know, images of a scene to be photographed are formed inverted and reversed upon the plate or film at its back. The optical mechanism of the eye operates in much the same way in producing a similar image upon the retina.

Rods and Cones

An image impinging on the mosaic of tightly packed light-sensitive cells, the *rods* and *cones* that constitute the up-ended nerve ends of the retina, causes impulses, probably of an electrical nature, to pass along the nerves from retina to brain. It is tempting, in the absence of a precise knowledge of the physiological reactions of the brain, to imagine the mechanism involved as being analogous to that of the television iconoscope and to conceive of the retinal mosaic being ' scanned ' and interpreted in some similar manner.

Acuity of Vision

Whatever this physiological mechanism may be and whatever the subsequent psychical phenomena by which the integrated impulses are translated into a visual ' awareness ', the important point to remember is that the thing seen is built up or ' integrated ' from all the separate reactions of each individual rod or cone. The implication of all this is that any object within the scene that can be viewed cannot be resolved into angular aspects narrower and thus of more acute resolution than those which correspond to the subtended physical width or diameter of the rod and cone concerned. From this it may be inferred that the *definition* of the thing seen, the *acuity of vision*, is limited. In other words, ' dots ' of light, shade and colour constituting the elements of the scene cannot be resolved further or separated as such if they subtend at the retina an angular span

substantially less than the width of the receiving rods or cones. A necessary corollary is that the detail apparent in a near object becomes progressively less as the object recedes.

The Yellow Spot

When an object is ' looked at ' or viewed, two movements are carried out by the eyes. In one of these both of the eyes are directed inwardly by a contraction of the appropriate muscles operating upon the eyeballs whose function it is to impart such an orientation when motivated by the brain, so that each eye is aligned directly upon the object. The image of the object is, in this way, brought squarely upon that most discriminating part of the retina residing at its centre and along the axis of vision which is known as the *yellow spot.* The retina is here somewhat thicker than elsewhere and at its centre is a small depression, the *fovea centralis,* where reside those retinal elements which alone are capable of resolving the received light impulses with sufficient acuity to discriminate the constituent elements of the viewed object so that it is *sharply* seen. At all other places on the retina, the clarity of vision is much less sharp and, even so, the definition of what is seen falls off rapidly as the distance of the location of the image away from the retinal centre increases. At the same time that this motion which converges the eyes upon the viewed object takes place, a further simultaneous muscular operation of the muscles acting upon the lenses of the eyes occurs whereby the curvature of its surfaces is changed so that the beam of rays entering the pupil of the eye are brought to a focus upon the retina.

The Crystalline Lens

It is this focussing feature of the crystalline lenses of the eye which differentiates the human eye so markedly from that of our box-camera analogue. There is no counterpart in photographic optics to this extraordinary ' automatic ' focussing feature by which without conscious stimulus these images are invariably maintained constantly in focus, whatever the distance of the associated object may be. Neither is there any parallel to the automatic eye convergence movement by which the eyes are ' toed-in ' so that their visual axes meet at the object directly

viewed whether its distance be near or far. These two movements of the eyes, which are involuntary in the sense that no conscious thought is involved in bringing them into action, play a most important part in stereoscopy and in the appreciation of depth, as will be seen later.

MONOCULAR FACTORS IN STEREOSCOPIC VISION

A comprehensive notion may now be formed of what constitutes the whole process of stereoscopic vision and what part is severally played by the many essential factors concerned.

Light Characteristics

In viewing a scene, or rather the various objects within it which form its detail, there are many factors which contribute in conveying a sense of realism to the thing seen. Some of these factors come into play even if the scene be viewed with only one eye. These factors, which are in the majority, might well be termed therefore ‘ monocular ’. Reverting for a moment to a consideration of a fundamental aspect of vision in general, it is almost self-evident that light rays are the vehicle by means of which the observing eye becomes aware of the thing observed and that the picture of this which is thereby ultimately formed in the brain is resultant upon the aggregation of stimuli emanating from every single discrete point and detail of every object constituting the scene. The visual contrast between the different parts of the scene which thus becomes apparent is the result, not only of the differences in the amount or *intensity* of the light reflected from each constituent point but also of the differences in that characteristic of colour, *hue*, which distinguishes it from white or grey, and also of that quality of colour *saturation* which resides in its distinctness, vividness or purity of hue.

If we were to take an ordinary black and white photograph of this scene, it would be reproduced only in various tones of grey varying from black to white. Of the three characteristics of colour constituent of the scene only the intensity or brightness of the varying details, that is to say their brilliance or lightness, can be differentially interpreted by those photographic tones of

grey to give that *contrast* by which alone constituent details of the scene can be successfully differentiated the one from the other. Some animals, cats for example, are capable of seeing only in terms of such tones of grey and to them the visual impressions must take on a strange black-and-white photographic quality.

It is convenient, in detailing the various factors which contribute to vision, to consider tones of grey as being the first of these. Such a conception is far from being foreign to human visual experience as those encountered on dull drab colourless days adequately testify. Using such an experience as a starting point in our review, let us see what additional factors can transform our mental reactions to such a visual response from one of flatness eventually to something rich, deep and vital.

From what has been said already, it is obvious that a change of light appropriate to finer weather conditions will add, to the vividness of our visual appreciation of the scene, the factor of *colour*, and with it the power to differentiate between various objects adjacent to each other which otherwise are to be discriminated only by their tonal differences in so far as contributing factors are concerned which have been mentioned so far. Making to ourselves a further mental reservation that we are restricting our analysis as yet to monocular factors only, we can visualize the brilliance which the viewed scene takes on and the greater distinctness with which objects within it stand out from each other if the sun is ' out ' and *sunlight and shade* are present. For in this event, not only are the scales of tones and colour extended but the distribution of sunlight and shadow contribute powerfuly in assisting us to determine, in the light of our past experience, the relative positioning of the details of the scene, limned as they now become in some semblance of spatial depth. If at this stage, we again take a photograph to point our meaning, we remember that vitality and an enhanced suggestion of apparent depth is conveyed by such *modelling* as we may introduce, either by taking advantage of sunlight and shadow in the open air or in the studio by use of the various types of artificial lighting.

Imagine now that in our search for the factors that are contributive to stereoscopic vision we are gazing at a landscape in its

full panoply of colour, light and shade. If the day be brilliant and the sunlight ' hard ' we shall be not so fully cognisant of the relative position in depth of the various ' planes ' into which the scene can be mentally divided as we would be on a ' softer ' day when *haze* is present. From experience we have become aware, even if only subconsciously, that the further away an object may be, the hazier it will appear on such a day. ' Distance lends enchantment to the view ' can, in one sense, be interpreted as a result of the transformation of the scene that can be attributed to this softening factor of spatial analysis that we call ' atmosphere '.

Movement

Now let us yet further vitalize our scene and set it in motion by moving ourselves and by including within it objects that themselves move. If we are changing our viewpoint by walking about or being transported by bicycle, train or car, foreground objects are relatively displaced more rapidly than distant ones. Similarly, the trotting horse or the wind in the trees lead to less change in the detail of the scene the further off they may be. Again experience has taught us subconsciously to associate scene changes due to relative motion as decreasing with distance. The contribution of this factor of *motion* to the overall stereoscopic appreciation of depth is a considerable one. That this is so can be adduced from the fact that two-dimensional motion pictures are so much more convincing than still pictures and can be very suggestive indeed of depth when the camera is bodily moved through, say, a close-up foreground of trees.

Accommodation

We have seen already that a contributory factor in the appreciation of depth resides in the *accommodation* or focussing of the eyes when some detail within the viewed scene is fixed upon as the object of immediate interest. We have become accustomed mentally to associate various values of accommodation with their corresponding variation in the distance of the object viewed and in consequence this information as to the particular

distance is subconsciously utilized by the brain in assessing or becoming aware of the relative distribution in depth of adjacent objects constituent of the scene when these are successively scrutinized. Regarded on its own merits as an isolated factor amongst those which we have classed as monocular, accommodation probably plays but a small part in supplying crucial informa-

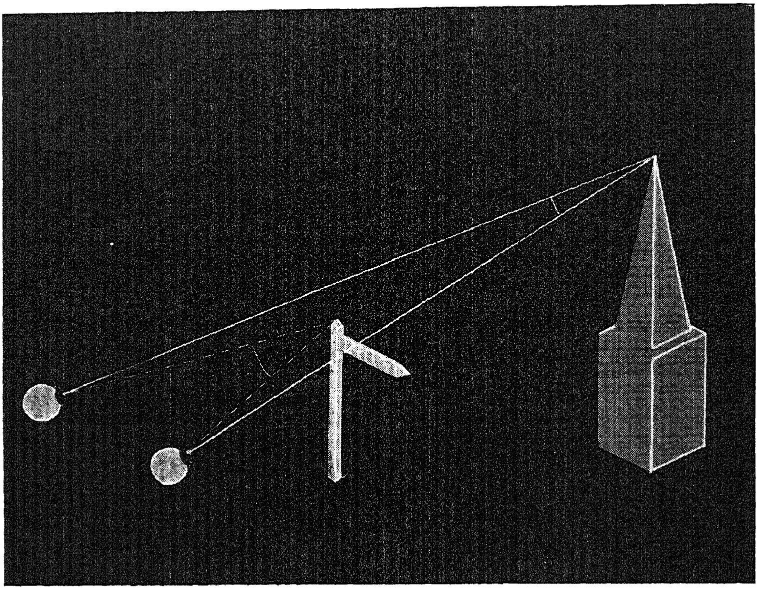

FIG. 1. *Convergence/Accommodation.* An important factor in gaining an impression of solidity. Two eyes, binocularly regarding a near object and a distant object, converge more for the former than the latter. The brain gets used to estimating distances subconsciously by the different amounts of convergence and accommodation for a near object and a far one.

tion in the sum total of that upon which the brain arrives at its synthesis of depth awareness from the evidence of the various factors received. As will be seen later, however, when the binocular factors come to be reviewed, accommodation when considered in working alliance with convergence can play a more positive part in natural stereoscopic vision. Unfortunately, however, it plays but a negative part in most stereoscopic photographic ' representations ' of the original scene.

Perspective

Of the monocular factors, we have now come to what perhaps is the most important factor of them all—*perspective.* The conception of perspective is a familiar one to most of us, especially so if we are adept at the representational arts of painting, drawing or photography, and a consideration of what this factor

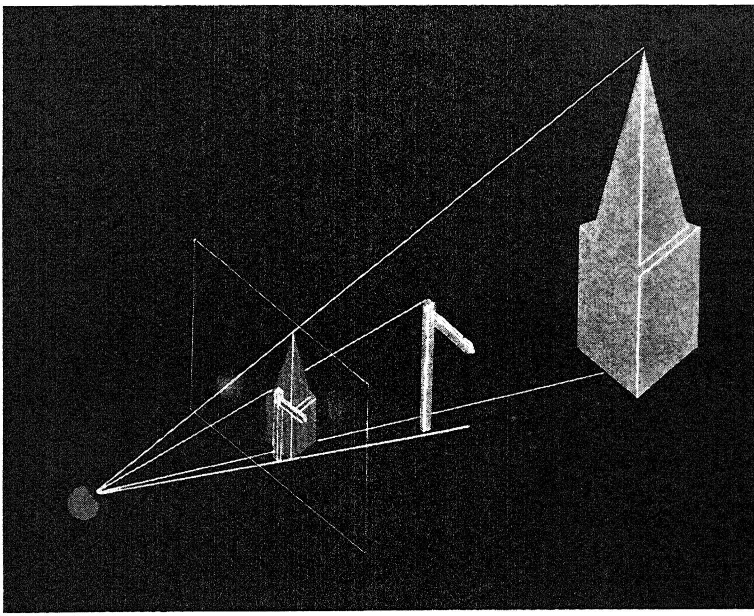

FIG. 2. *Perspective.* The eye, viewing two objects of different sizes at different distances, may register their images as being of nearly equal vertical *span.* The intercepts of the angular sighting lines, projected on a transparent plane, are a measure of the respective *perspectives.* The overall picture thus projected on a plane is a *perspective drawing.*

really is, and its importance, can best perhaps be got in terms of these familiar arts.

Let us take the problem of the artist or photographer faced with representing on a two-dimensionally flat piece of paper or film a three-dimensional scene. The artist would unconsciously set up in his mind's eye a transparent sheet identically situated with his easel; the photographer looks through his view-finder,

which can be in essence a replica of his camera. On his transparent easel the artist visualizes its intersection with all the incoming light rays that emanate from every detail within the scene that is to be faithfully represented, which thereafter impinge upon his mind's eye, necessarily cyclopean. Such intersections are sketched on the paper and constitute what is known as a ' projection ' of the scene on the plane of the paper, and we can say that a drawing has been made of the ' perspective ' of the landscape as seen from the artists' single-eyed stance. The drawing, as described, is nothing more in fact than a sketched-in record of the intersection of all the rays in the cone of light from scene to eye on a plane at right angles to the central line of sight. Similarly the photographer's viewfinder or ground-glass screen makes instantly visible the same record, but in this case painted in by the light rays themselves. If the artist has done his job consummately well and the photographer has exposed and processed his film correctly, either picture can satisfyingly and faithfully reconstruct the original scene in its correct ' drawing ' or perspective if the facsimile be looked at from the same distance as that from which it was ' taken ' for, from this position, it will subtend the same angular cone of rays as did the original scene.

Relative Perspective

In essence we are stating that in seeking a suitable definition of the word, our immediate purposes are served if we regard ' perspective ' as the drawing-in of the intersection of all light rays from the scene to the eye upon a plane at right angles to the centre line of sight, and we have seen that the perspective of the elements within a scene will be different if the distance of this plane from the eye or lens be changed. Not only, in this event, will the overall drawing or perspective have a different ' aspect ' but the *relative perspective* of one element of the scene with respect to any other will be different. The perspective of a painting or photograph is unique for the particular stance from which it is painted or viewed and there is only one correct distance from which the resulting picture from either can be subsequently viewed if the reconstruction is to be completely satisfying.

There are some further important inferences to be drawn which a simple example will illustrate. Imagine that we are taking a photograph of, shall we say, a foreground signpost and a church steeple in the background. If the camera be situated appropriately near enough to the signpost, it can be arranged if required that the top of the post is in line with the top of the steeple, and the resulting photograph will record the two as being apparently of the same height. In subsequently viewing the photograph, because our experience tells us that the two are of quite dissimilar heights, we register the intended reaction that we are looking at a representation of the church and steeple with a signpost included in so near a foreground that both appear to be of the same height for ' effect '. We know incidentally that had the photograph been taken from further back, the recorded relative sizes of post and steeple would have appeared less abnormal. Supposing, however, that the intended effect of similar apparent size was a prerequisite but that a camera stance sufficiently close to the signpost was not possible for some physical reason or other and that we attempt to get the same final result from further back by using a long focus or telephoto lens. What will happen of course is that, with the narrower angle of view of the new lens, the apparent size of the signpost relatively to the size of the film can indeed be restored but that the steeple too has increased in apparent size disproportionately and is out of the picture. We have not succeeded in our immediate task but at least we have demonstrated two things. Firstly we have convinced ourselves that only at one place, from a unique stance, do steeple and post subtend the same angle and register equality of perspective in height. Secondly, we are reminded that all lenses, whether wide-angle ' normal ' or telephoto, will record identical perspectives from the same view-point and that they differ only in their angle-of-view and therefore in their required function of altering the recorded apparent size on the film so that the object of major interest may for example ' fill the plate '.

It is to be remembered then, especially when we come to discuss shortly the impact of convergence and parallax where vision is binocular, that a ' perspective ' once photographed on the film is immutably recorded and is unchangeable; that it is

appropriate only to a reproduction of the original scene photographed from one particular and ' unique ' standpoint; and that, as such, it must be viewed in its reproduced form in precisely analogous circumstances to those which prevailed when the picture was taken if the resulting visual response is to be identical with that experienced when viewing the original scene.

BINOCULAR FACTORS IN STEREOSCOPIC VISION

So far we have considered in detail only monocular factors which, although contributing to the grand sum of psychophysiological response that aggregate to give adequate visual perception and contribute to a better perception of depth, are nevertheless derived from the reactions of each of a pair of eyes considered separately. If we were now to ignore the further contribution which *binocular* factors might make, where the impact of two eyes in combination is to be assessed, we should be justified in concluding that the normal person with two eyes would be little better off than an abnormal person with virtually only one. In one respect indeed, the one-eyed person would be better off in that he would have perforce accustomed himself to looking at pictures and photographs with the one eye appropriate to two-dimensional reproduction of three-dimensional scenes originally viewed, by the artist's cyclopean mind's eye or taken with a one-lens camera, and would thus be accustomed to seeing them in the correct perspective.

The contribution to the perception of depth which two eyes in combination can make, however, is transcendent, and surpasses all the rest. The two factors concerned can conveniently be taken separately in spite of their close inter-relation.

The Mechanism of Convergence

The first of these is the *convergence* of the eyes when actively looking at an object which has been mentioned earlier in association with that accommodation or focussing of the eyes with which it is almost invariably accompanied.

When an object is being specifically ' looked at ' in Nature, we unconsciously bring together or ' toe-in ' the optical axes of

our two eyes to converge upon the object. As the eyes are separated horizontally by a discrete distance, they can be considered as being at the two ends of the base of a triangle whose length is equal to this 'interocular' distance, the two other sides of the triangle being constituted by the two rays passing from the object to each separate eye. If the object is a long way away, at 'infinity' as we say, the triangle would have lengthened out inordinately and the two rays would be sensibly parallel. For a nearer object the angle through which each ray would have to bend inwards to converge at the object apex of the triangle would be the angle of convergence of each eye appropriate to the distance of the particular object concerned, whilst the angle at the apex of the triangle would equal the sum of these two individual eye convergencies and is thus the total convergence of both eyes taken together as a pair.

In our everyday visual experience we are without doubt subconsciously used to associating a definite degree of exertion in the muscles which converge the eyes with the particular distance of the converged-upon object which calls up the effort. In consequence, the degree of convergence brought into play is an important factor in the estimation of distance and one which is therefore instrumental in arriving at a still more exact appreciation of depth than that which even all the monocular factors in combination can give alone without it. The analogy of the eyes in convergence to the principle of the range-finder is a close one but, whereas in the range-finder angles of convergence can be measured in effect with considerable accuracy, it is unlikely that the corresponding eye-convergence 'mechanism' is capable of much more than a fairly rough comparison of related distances. Indeed, as will appear later in this development of the role of binocular factors in stereoscopic vision, it is the writer's opinion that the main contribution of convergence is in determining the location or positioning of the 'scene-as-a-whole' rather than in interpreting those nicer distinctions of relative distances subsisting between the various component objects of the scene which make it up.

Certain aspects of convergence, which distinguish it from its parallax derivative which is to be discussed later, are of great importance and should be examined carefully if confusion

between the contributions which each can make to stereoscopic vision is not to ensue.

The Consequences of Convergence

These aspects or consequences of the nature of convergence can best perhaps be examined by a detailed consideration of what would take place if we ' converge ' two identical cameras in imitation of the movement of convergence of two eyes. Let us imagine that we have two cameras, whose lenses are spaced at the interocular distance, aligned in the first instance so that the two optical axes are parallel. The cameras in this set-up have zero convergence and are thus aligned on a hypothetical object at ' infinity '. The two images of this ' object ' are formed at the centre of the film at the back of the camera in each case. Both cameras are accepting similar angles-of-view and the various objects within the scene embraced by these angles are imaged across the width of each film symmetrically on either side of their centres. Let us picture to ourselves what happens as both cameras are swivelled as a whole equally in opposite directions towards each other about a vertical axis through the centre of each lens to converge in a similar manner to the eyes on successive objects in the centre of the field or angle-of-view as the intersection of the two optical axes approaches the cameras from infinity. This intersection, which is approaching along a line bisecting the base-line between the two cameras and parallel to the line of sight, subtends a gradually increasing angle of convergence to the two cameras; the images of the successive objects, appearing at this intersection as the cameras are constantly toed-in to suit, being formed always at the centre of each film. It is easily visualized that, whilst this is happening, the images of the original object at infinity have now drifted off to either side, that in the left camera to the left of the centre and that in the right camera to the right. What in fact has happened is that, in both cameras, the complete images of the scene-as-a-whole that is embraced by the respective angles-of-view have been displaced bodily outwards in opposite directions across the faces of the films. We have actually done nothing more than, in photographic parlance, ' panned ' the two cameras in opposite directions across the field of view.

This being so, it is obvious that the pictures which would be recorded by either film differ not at all from each other in any respect whatever except that they are differently ‘ centred ’ with respect to camera and film and they are thereby differently ‘ framed ’ at the side edges, as the outside strip of each picture is ‘ panned-off ’ the corresponding edge of the film and the previously unrecorded new marginal strips of the picture are ‘ panned-in ’ to appear at the inside edge of each film.

In the cameras therefore, convergence achieves nothing but a centring of the recorded picture on the point of intersection of the toed-in optical axes and a masking-off of the recorded scene at the edges symmetrically about this centre to correspond.

The sole function of convergence in the camera is thus the location of the point of intersection of the optical axes in any given plane within the scene at right angles to the line of sight in order that the two angles-of-view may coalesce to set up a so-called ‘ frontal plane ’ and thus to give coincident margins at this point. Such a disposition ensures that in subsequent projection, where the two projectors are toed-in at the screen to give also coincidence of images without marginal waste, the frontal plane is located apparently within the plane of the screen.

Parallax

We come now to the second binocular factor, *parallax*, and later to a consideration of the ‘ disparate ’ images to which parallax gives rise. Both are of supreme importance in any consideration of stereoscopic vision for indeed, without that parallax-derived disparity of left- and right-eye images that is the characteristic of binocular vision, an appreciation of stereoscopic depth in the true sense of the term is impossible.

As will be seen, parallax can be defined or measured in terms of angles of convergence, and it may be for this reason that the two are so frequently confused either as being to all intents and purposes synonymous or in possessing some vague attributes in common. The two are in fact quite dissimilar. Convergence, as we have seen, is nothing more nor less than a ‘ toeing-in ’ of eyes or lenses for the sole express purpose of centring the whole image of the angle-of-view effectively, economically and without

waste on retina, film or screen as the case may be. What then is parallax? Let us first define it in general terms and from thence go on to a consideration in detail of 'relative' parallax, which is the important thing.

Parallax Defined

Parallax then can be defined for our purposes as the lateral shift or displacement of the image of an object on retina or

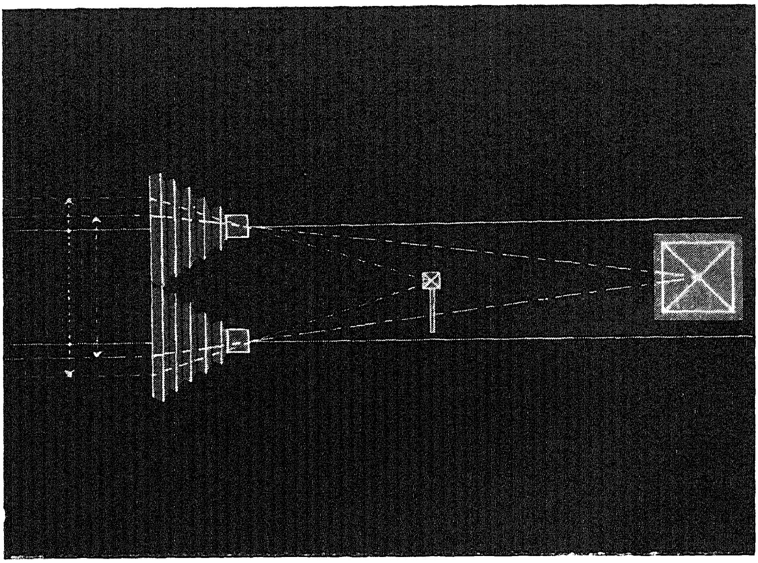

FIG. 3. *Parallax* Two cameras or two eyes, spaced at the *inter-ocular* distance, will show different displacements from the centre line of central objects at different distances. These lateral displacements are a measure of the parallaxes of the signpost and steeple shown and lead to the characteristic shift in the resulting *disparate images* which are all-important in measuring depth.

film if the location or stance of the viewing eye or lens be shifted along a line at right-angles to the line of sight. In the illustration at Fig. 3, two cameras with lenses laterally spaced at the interocular distance will record at the centre of their respective films those parallel central rays proceeding from an object at infinity which lie along their optical axes. If now we consider two similar rays which proceed from an object in the middle

distance, our church steeple for example, the respective images in the steeple will be cast further apart than were those of the ' infinity ' object; that in the left-hand camera to the left of the centre, that in the right-hand camera to the right. The sum of these lateral outward shifts or displacements is a measure of the parallax of the steeple as apparent at the location of the cameras and whose lens separation laterally is of the particular value shown.

Relative Parallax

If now two further similar rays proceeding from a still nearer close-up object, say our signpost, are traced in we find that the images of the post are thrown further outwards from the centre of each film than were those of the steeple. Again the sum of these two outward displacements from the corresponding centres measure for us the parallax of the signpost under the same conditions of camera stance and lens separation as before. The important thing that has now to be said is that the difference between these two sums, that is to say the difference between the two ' absolute ' parallaxes, as they are termed, of steeple and post is a measure of the *relative parallax* subsisting under these same conditions between the steeple and the post.

Parallax in Vision

We should now pass for a moment, from this consideration of the recording of parallax shifts in the camera, to the analogy of what happens in the eyes under similar conditions. It is obvious that in the cameras of the eyes precisely similar ray distributions will occur. But we remember that, in the case of the eyes, it is only those image details which are cast directly on the super-sensitive central part of the retina at the back of the eye, the ' yellow spot ', that are clearly seen with maximum acuity of vision. We remember too that, on this account, the eyes are converged upon the object of immediate interest to be viewed. In other words, as we have seen, the ' optical axes ' of the two eyes are aligned to intersect at the object so that the two rays proceeding from it are received centrally by each eye and in each case fall upon the sensitive yellow spots.

Parallax in Action

We can now see what will be happening within the eyes in the particular circumstances detailed in our camera analogue. When looking at church steeple and signpost, we shall be unconsciously flirting our gaze from one to the other, usually with a rapidity of which again we are little aware. In doing so the necessary changes in convergence are the means by which these are carried out and such changes are incidentally accompanied by alterations in the accommodation of the eyes to suit. Let us slow down the process and examine in more detail what is going on and what consequence in the resulting mental reactions are to be expected. Imagine then we are ' steadfastly ' gazing at the church steeple. Suitable convergence of the eyes has placed the images of the steeple centrally on the yellow spots and the steeple is seen clearly. This convergence has swung or ' panned ' the whole image of our complete field-of-view so that in each eye the rays from an object at infinity along the line of sight have been displaced to lie laterally inside those of the steeple, whilst those from the signpost are lying laterally outside. In saying and visualizing this, we make the point again that the relative positions of the three images in each eye have not been changed in any way, the one with respect to another, in swinging the image of the whole scene in view across the retina by convergence movements. In this momentary ' fixed ' gaze at the steeple the image of the signpost, albeit hazy and ill-defined owing to the lesser acuity of vision associated with those non-central parts of the retina away from the yellow spot upon which it falls, will be cast in the left eye to the left of the image of the steeple and in the right eye to the right. At least in this respect therefore the visual impression of the scene as viewed by the left and right eyes will be different.

A moment later perhaps our direct gaze will have been involuntarily turned to converge upon the signpost. Now it will be the images of the post that will be centred and viewed with clarity whilst those of the steeple will have been swung across away from the retinal centres towards each other in the wake of the images of the ' infinity ' object. Again, the left- and right-eye overall images are dissimilar.

Disparate Images

Whether our direct gaze be fixed on the steeple or the post of our example, the brain reacts powerfully to this dissimilarity in the two left- and right-eye images and from long usage registers a strong awareness of the difference in the distance away in depth of the two objects responsible for this disparity in the associated images. This difference between these parallax engendered *disparate images*, as they are called, constitutes the supreme factor of all those visual impulses that the brain interprets which are instrumental in its function of perceiving and assessing stereoscopic depth. So potent indeed is this one factor that, at least in the writer's opinion, no persistent conviction of true depth, especially in would-be ' true ' stereoscopic projection, is possible without it.

CHAPTER II

THE GEOMETRICAL REQUIREMENTS OF STEREOSCOPIC RE-PRESENTATION

THE cerebral ' mechanism ' by which the brain reacts so powerfully to these disparate images of ' homologous ' points is as yet very much an unknown quantity. It is as though the brain were always taken by surprise at any dissimilarities in the two images and that in consequence of being ' off its guard ' its reactions were of a more intense order than those resulting from the more palpable monocular and convergence factors.

NATURAL VISION AND UN-NATURAL RE-PRESENTATION

' Interocular ' Variations

Whether this conception be a fanciful one or not it is a fact, and one which needs little or no demonstration, that an abnormal amount of disparity between the two images will lead to mental reactions in nearly every instance which are sufficiently strong to establish an over-riding tendency to discount the evidence of all the other factors which may otherwise contribute an impression of normality in the appreciation of depth. If for example in taking stereoscopic photographic pairs, the camera lenses are spaced at an interaxial distance substantially more or less than that of the normal interocular spacing, then in subsequent projection the sense of depth conveyed to the viewer by the resulting abnormal image disparities is respectively either excessive or deficient. For two rays converging on an object from two points spaced at interocular distance apart will, if produced backwards, preserve the same angle of convergence provided the lens spacing is correspondingly increased to span the rays; or, alternatively a decreased lens spacing will span the rays at a point nearer to the

object. Thus by the artifice of increasing the lens separation we can, with a reservation to be mentioned later, reproduce the image disparities that would have been observed from a visual

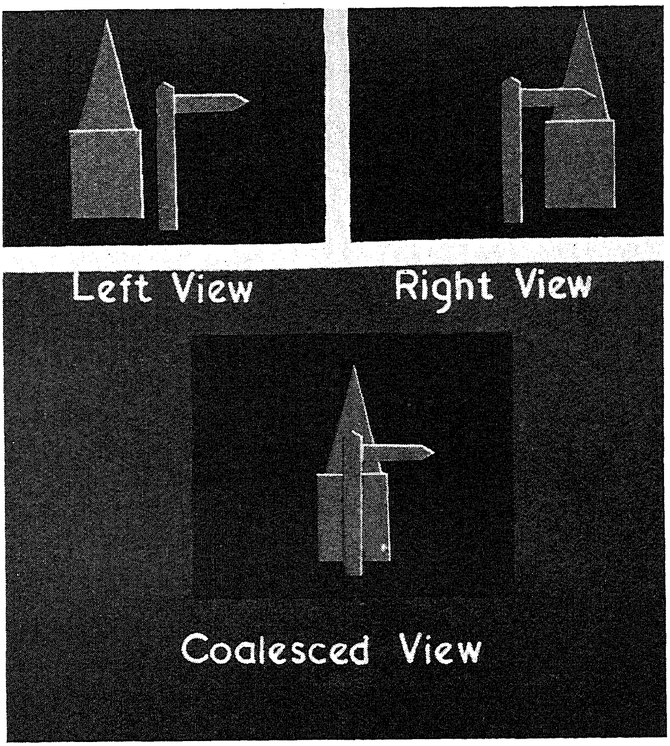

FIG. 4. *Disparate Images.* The top pair of pictures represent the images cast on the retinas of two eyes when binocularly regarding a near signpost and a distant steeple. The images show a *disparity* and it is this difference due to the two separated eye stances that the brain, through long experience, integrates into the impression of depth represented below. Note that the latter is what we imagine we see. In fact, if gazing at the signpost, two separated images (phenomenon called *diplopia*) of the steeple are visible; as can be confirmed by those possessing the knack of seeing stereo-pairs (top pair) with the unaided eyes.

stance nearer to the object than that of the camera and thus reproduce in subsequent projection the more marked apprecia-tion of depth that is apparent in an object which is nearer to us. In a similar way, by decreasing the lens separation, we can

simulate the less marked appreciation of depth apparent in an object that is given by a visual stance further off than is the camera.

Later on it will be seen that this artifice of varying the camera lens spacing in order that a corresponding variation of parallax, and hence of its derived disparate images, is adopted in many systems of stereo projection to overcome certain fundamental drawbacks inseparable from those practicable basic methods of projection which are dealt with in Chapter III. For the moment it will suffice merely to draw attention to the basic deficiencies attendant upon the artifice of a change in lens spacing. These have already been inferred when we temporarily neglected, a little earlier on, any discussion of the inevitably conflicting effect that non-variation in *perspective* would present when, from a fixed viewing stance, parallax alone was being varied by a change in the separation of the lenses.

Invariability of the Photographed Parallax

In this connection it should be realized, once we have taken a picture in our camera, that just as perspective in the scene is unique to the particular stance from which it was taken at a particular instant in time, and is furthermore one that is immutably recorded and unchangeable, so it is the same for the scene parallax. Since the relative parallax of an object taken at random within the scene is measured, as we have seen, by the relative displacement of the object's images as recorded on the two films—the one with respect to the other, or both with respect to some arbitrarily chosen point such as the centre of each film—then, as the photographic recording cannot change, so also must the recorded relative parallax remain unchanged. This will be so even if, in subsequent projection, we vary the convergence of the projectors for, again as we have seen, a variation in convergence achieves directly nothing more than an angular panning or translational shift of the two images as a whole with respect to each other, altering not at all the relative distribution of detail within the images appropriate to the various objects which collectively constitute the scene as a whole.

With the help of Fig. 5 it will now become evident, if parallax or perspective be varied independently of each other without

correlation, that a pair of images will be recorded in the camera which, in subsequent projection, will inevitably reproduce the scene in a false and unnatural aspect.

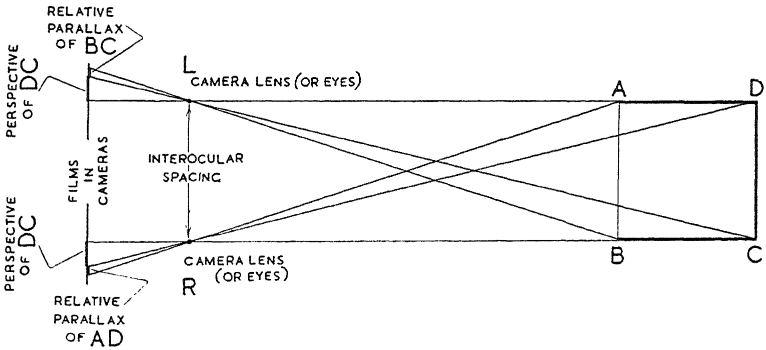

FIG. 5. *Relative Parallax and Perspective.* Two lenses, or two eyes, at normal interocular spacing view a square (base of cube) of interocular dimensions (for simplicity of diagram). The immutably recorded dissimilarity of the two disparate images of the square in *depth* due to differing (equal but opposite, in this case) relative parallaxes, uniquely associated with an interocularly spaced viewpoint, contrasts markedly with the (immutably recorded but) identical *width* of the square in perspective, seen by either eye.

Illustration of Parallax/Perspective Variations

As the point to be made is an important one, let us examine the figure with some attention. Here we have imagined a stance, located roughly at the centre of the figure for convenience, from which a pair of camera lenses, whose optical axes are separated by the normal interocular distance, ' view ' a particular object in a given scene. The object chosen is, let us say, a cube. To simplify the drawing and the explanation, only the square top (or bottom) of the cube is shown and the square is taken as lying in the horizontal plane which contains the two lens axes. Again to make the argument simpler, the length of the square's side are taken to be equal to the interocular spacing of the lenses. If the nearest side is ' four-square ' to the camera lenses and is ' central ' with respect to their optical axes, it follows that each lens ' looks ' along the length of one side of the square. Thus to either lens, one side of the square would be colinear with its axis and would appear and be recorded as a point; whereas

the other side would subtend an angle, whose magnitude would be dependent on the length of the side in depth and on its distance away, and would appear and be recorded as a short horizontal line on the film. One side of the square having being recorded as a point by one lens, then the length of the line-image recorded by the other lens of the same side, whichever lens be chosen as the point of reference in this particular example, is a measure of the relative parallax ' in depth ' of the sides of the square.

In these same circumstances, and from the same chosen stance, it will be noticed that, to either lens, the near (or further) side of the square which is at right angles to the line of sight will also subtend an angle and appear and be recorded as a line on the film. Both lenses, in the particular circumstances drawn in the figure, will record line-images of this near (or further) side of the square. Either of these lengths can be regarded as a measure of the ' perspective ' or apparent width across the field of view of the square.

Reverting to the visual analogue, if we had been looking at this square with our *eyes* from the same stance, similar point- or line-images of the two types we have just dealt with, appropriate to the sides of the square running away from us in depth and to those across our field of view respectively, would be thrown on the retinas of our eyes. The images would be similarly located with respect to each other as described for the camera-lens example and the ratio of their lengths and distances of distribution with respect to the centres of the retinas would be the same. Our brains would translate the corresponding retinal impulses received into a visual perception of the square. By virtue of its long practice, the brain subconsciously interprets the disparity of the ' point ' image in one case, as against the ' line ' image in the other, as seen by one or other of the *two* eyes in looking at the sides of the square which recede away from them, as parallax-derived disparate images, appropriate and natural to these particular lines receding along the line of sight. The brain is, in fact, able after its long experience to assess the actual physical length in depth of these receding sides. Simultaneously also the brain registers those different line-images due to the near (or further) side of the square which are of the same length in *either*

eye. These images, again through long experience, are accepted as appropriate to the aspect in perspective of a line which runs across our field of view which has no recession away from us in depth.

At this stage we should remind ourselves that disparity of image and its attribute of depth assessment is due to the relative parallax as between two eyes, whereas it is rather the similarity of the two images which is of the essence of that span of images in width and height which we have somewhat loosely termed ‘ perspective ’. The two phenomena are nevertheless alike in being unique to a given viewing position, and alike in being immutably recorded on the film in the camera, once and for all, when the photograph is taken. No subsequent manœuvring of convergence in projection is able to change a recorded parallax or perspective in any respect whatever.

Effects of Departures from Natural Vision Conditions

The consequences that must follow upon any departure from a natural association of that normal parallax and normal perspective which is appropriate to a given stance may now be perceived. Suppose for example, as in Fig. 6, for some reason or other we decide, whilst yet retaining our initial stance at its original distance from the square, to reduce the relative parallax. This can be achieved, as will be seen from a mere inspection of the figure, by a reduction in the interaxial distance separating the two lenses. If, as in the illustration, we reduce this by half, it becomes manifest that at the new relative position of the lenses that have been moved to achieve this the angles subtended by each end of the recording side of the square have both been reduced approximately to half their previous values. Consequently the difference between them, which is the angular ‘ aspect ’ in depth of the side, has also been reduced to roughly a half. From this it follows that the parallax displacement on the film has, in its turn, been similarly reduced and thus that the relative parallax subsisting at the new lens positions is only a half of what it was before. The consequent disparity between the two new corresponding images is less conspicuous by a half of what it was before.

If we were now to sketch in, at half the distance of the observed

square from our viewing stance, another similar square, it would be observed that the angular aspect of the square's receding side would be roughly twice what the original square subtended. A side of only half the original length would however subtend approximately the original value of aspect angle. Such an angle, as before, would also produce a displacement on the film as

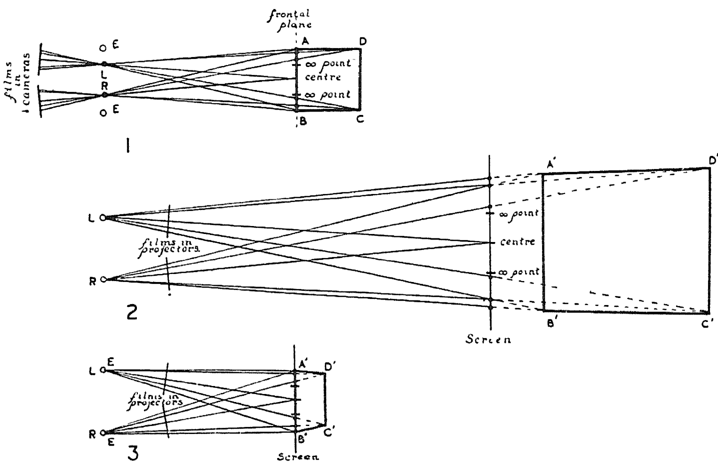

FIG. 6. *Parallax Variation; Reduced 'Interaxial'*. The square (base of a cube) in 1 is photographed by two lenses, *L* and *R*, spaced at half the interocular distance *EE*, to form images of its corners spaced on the camera films as shown. In 2, the images are projected on the screen which, to eyes situated interocular apart at *L* and *R*, appear as from a remoter larger square. If the convergence is increased as in 3 to bring image as near as original object, it takes on appearance of a flattened, distorted rectangle.

between its front and back end of a length identical with that previously recorded and in consequence the relative parallax and hence the disparity of images as between the two eyes would be indistinguishable in this respect from those associated with the original square.

In the meantime, however, when reducing the interaxial spacing of the lenses, no change whatever has been effected in the lengths of the 'perspective' images of the sides of the original square at right angles to the line of sight, as recorded on the film of either camera by either lens, owing to the fact that their apparent angular 'width' still remains precisely the same.

Mental Reactions

When therefore in a projected reconstruction of the original scene, a mental synthesis is attempted, two conflicting types of evidence have to be reconciled. In one of these, the disparity between the two reproduced images is appropriate to that of a square of only half the depth of that of the real original, whereas in the other the message of perspective is that the width of the sides of the reproduced square at right angles to the line of sight is identical with that of the original.

The reconciliation arrived at by the brain in face of those two conflicting messages could only be a compromise answer to fit the observed facts so far apparent in the projected reconstruction. The brain will tend to accept the evidence of perspective by assessing the width of the projected square as being identical with that of the actual original. Perspective, however, has nothing to say which has a direct bearing on depth perceptions and the brain has little option in accepting the evidence of the parallax-derived reduced disparity of images in assessing the apparent depth as only half of that of the real square. In consequence, its only possible rational reaction in combining the two conflicting messages is to arrive at the conclusion that the projected reproduction is that appropriate to a 'near-rectangle', and not to a square, whose depth along the line of sight is only half that of its width across it.

But this is not the whole story of the mental reconstruction derived from the projected evidence. As yet we have not decided at what apparent distance the brain will conclude the reconstructed square to be. What are the further factors that can influence the conclusion arrived at; how are they conducive in this and to what degree?

Contribution of Perspective

Let us first see whether perspective can provide other evidence than what it has done already. We have seen that perspective and parallax have so far presented the appearance of the reconstructed square as that roughly of a rectangle. In other words the original square has been apparently flattened in depth. But we are accustomed, when viewing familiar objects, to associating a reduction of depth with their recession away from

us, owing to the reduced parallax involved. That this is so can be deduced from an inspection of the illustration, Fig. 6. Here it will be seen that if one of the receding sides of the original square subtends an angle at one of the eyes or at one of the camera lenses, this same side being as before ' in line ' with the other eye or lens for simplicity, then the corresponding side of a square or rectangle which is to subtend half this angle and one which consequently gives rise to a parallax displacement on the film of half the previous one whilst yet preserving its actual length in appearance, would be situated at twice the distance of the original square, as shown. As far therefore as we have examined the further evidence-contributions of the geometrical factors concerned, the brain has the choice of deciding that the reconstructed object is either a ' square flattened in depth ', i.e. a rectangle, at the same distance as that of the original object, or a largely undistorted square of the same shape as the original but at twice its distance. Between these two choices, or something intermediate between the two, the brain would normally be likely to accept the latter solution from the evidence of perspective where the object is indeed a familiar one, if the further contribution which the convergence factor might play is ignored for the moment and regarded as of a value that would be non-conducive. That this is so can be seen from the fact, brought out in the Figure, that the perspective view of the ' width ' of the front face of the reconstructed square is appropriate to either a face of the original square at the original distance or to a face of twice this size at twice this distance; or, put another way, a face of a size corresponding to the apparent distance. But the evidence of the familiar form of the familiar object is strong and a solution which grants the accustomed ' square shape ' at nevertheless a distance of twice is likely to be more acceptable than one which credits a flattening distortion at the nearer and albeit more probable correct distance.

It is at this point that the supplementary value of such evidence, as will be contributed by the convergence operating at the time of viewing the projected reconstruction, might be considered as likely to be a determining factor in the brain's final conclusion as to what the apparent state of affairs really is, or is most likely to be.

Resolving Contribution of Convergence

In the illustration, Fig. 7, let us see what effect on the final answer variations in the convergence imposed in viewing the projected image can make. If here we concentrate on one corner of the square, say that at one side of the front face—arbitrarily chosen as a reference point in assessing the distance

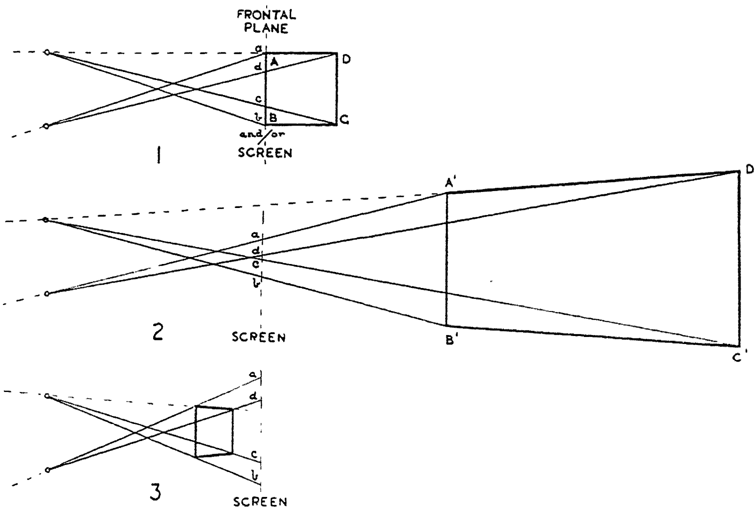

FIG. 7. *Convergence Variation.* The square, photographed in 1, with the convergence shown is thereby located in the 'frontal' plane so set up. If the consequent images on the films are projected with the same convergence, the images *a*, *b*, *c* and *d* of the square's corners *A*, *B*, *C* and *D*, respectively formed on the screen, appear to 'place' the reconstructed square, same size, same distance as the original. If the convergence is decreased, as in 2, the corner images appear to reconstruct an elongated 'square' further off—the scene, in other words, is pushed back. In 3, an increased convergence brings the scene forward to reconstruct a shortened, distorted 'square'.

of the 'square' as a whole—it will be seen that we can take this corner of the original square as subtending an angle at our two 'range-finding' eyes or camera lenses. We have seen previously that a 'change of convergence' amounts to no more than a 'panning' of the viewed image as a whole across retina or film as the case may be. In the film already taken by our camera, whilst the relative positions of the details constituting

the photographed scene with respect to each other are immutably recorded, the particular overlapping section of the whole sweep of the landscape or scene that is to be seen or recorded by eyes or camera can be altered by a convergence or toe-in of the eyes or camera lenses. Similarly in subsequent projection, as the illustration shows, we can swing our projectors, or otherwise cause our two projected pictures to be swung across each other on the screen, so that in effect the two constituent pictures are brought into coincidence in any plane we care to choose at various distance from the viewing eyes. If, for example, our effective viewing distance is equal to that from which the original object-square was viewed and taken, then the convergence in viewing would be identical with our original convergence angle. If, however, the convergence angle be halved then the two left- and right-eye views would appear to be merged into coincidence at twice the distance of the original square and its reconstructed image would therefore appear to come from twice as far away.

Synthesis of the Three Conflicting Reactions

Is the final answer at which the brain arrives in our present example, in view of this supplementary evidence, likely to be influenced by this *distance* testimony of convergence? If the applied convergence effective during projection is that appropriate to an image at the same distance as that of the original square then the brain will in all likelihood decide that it is seeing a square flattened in depth, i.e. a distorted rectangle, whose front face is of the same width as that of the original square, the whole being at the same distance as was the original. On the other hand, if the convergence imposed in effect during projection-viewing is but half that of the original, then the brain's conclusion will in all probability veer in favour of a slightly distorted square of the same 'shape' as the original, but of enlarged size and situated at a greater distance.

It is particularly to be noticed that in neither case is the viewed reconstruction after projection a facsimile one. Neither reconstructs the original truth, and we are thus brought face to face with a most important conclusion. Remembering that perspective and parallax are recorded immutably on our film in

taking, once and for all, it is clear that the only geometrical factor we can vary, in taking from a given stance and in subsequent projection and viewing, is convergence. The inevitable consequence and conclusion is that, if the parallax in taking be other than normal and thus contradictory to its associated normal perspective from a given stance, no variations in the accompanying imposed convergence during taking or subsequent projection—the only variant open to us—can modify or recreate the viewed-and-projected scene back into identity with the original.

SUMMARY OF STEREOSCOPIC NATURAL VISION FACTOR VARIATIONS

We can now profitably attempt a summary as to what will happen if, in projection we vary nevertheless, intentionally or unintentionally, the three geometrical factors of parallax, perspective and convergence independently of each other from what they normally are in ' straight ' vision.

Parallax

The important feature about Parallax, it will be remembered, is the ' disparity ' of the two images to which it gave rise in binocular vision. The importance of recording disparate images, which are those arising from the parallax arising from two eyes or cameras at the interocular distance, can be realized by the simple experiment of projecting a film taken with say half the normal interocular. No manipulation of projector objective convergence, or variation in viewing convergence, will restore the missing and necessary factor of retinal images which differ in that essential degree of disparity which the brain associates with normal viewing when the eyes are separated by a normal interocular distance. The picture is flat; and no subsequent convergence variation can add, at most, more than an unconvincing specious illusion of greater solidity. In other words since binocular parallax, the controlling function in the recording of disparate images, is ineradicably fixed on the film when taken, nothing can subsequently alter it or replace its inadequacy. If

the camera separation is nevertheless *varied*, the subsequent effect on the screen can be forecast from parallax considerations. Thus, if the separation was less than interocular, then the disparate image relief recorded will necessarily be that normally

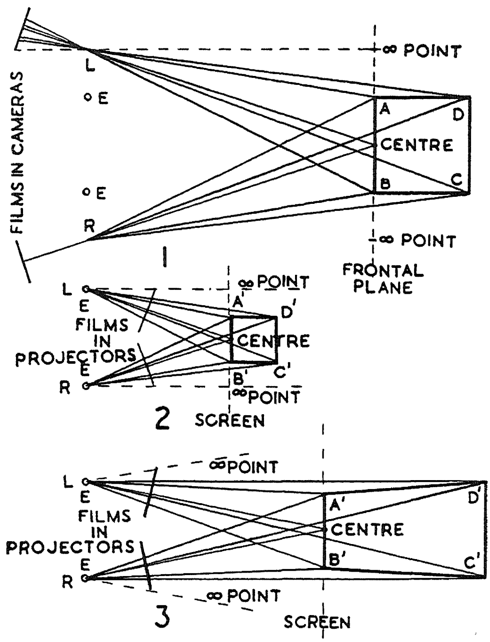

FIG. 8. *Parallax Variation; Increased 'Interaxial'*. The square *ABCD* in 1, photographed by two lenses, *L* and *R*, spaced at one and a half times the interocular distance *EE*, forms images of its corners spaced on the camera films as shown. If projected without effective change in convergence as in 2, the reconstructed square on the screen appears smaller and nearer. If, as in 3, the convergence is decreased to place the image at object distance, the square appears to become an elongated one of exaggerated depth.

associated with an object further away. But if the other geometrical factors, particularly that of perspective, are normal in the reproduced scene, then, in reconciling the conflicting evidence the brain arrives at the conclusion that the stereoscopic illusion presented is one which reproduces a distorted object of reduced depth, accompanied by a contraction in depth of the whole scene.

Perspective

Dealing next with the results of *variations* in Perspective, if we recapitulate for a moment, we remember that just as the appreciation of ' depth ' in a scene is dependent upon an angular

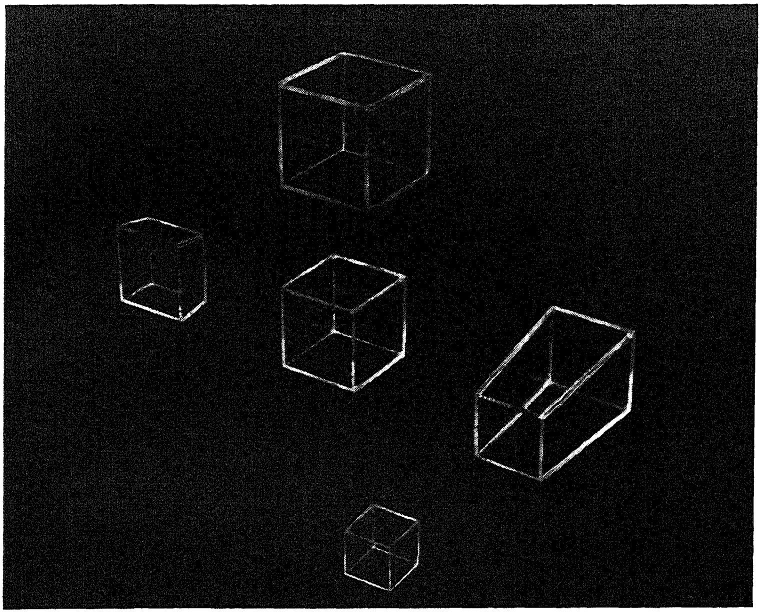

FIG. 9. *Distortion in Projection/Viewing.* The cube in the centre represents the photographed object, and also its image, if projected and viewed to give identical parallax and perspective. The ' cubes ' on the left represent typical distortions following a reduced camera interaxial—between either enlargement in size apparently further off (' giantism ') or contraction in depth (' flatness ') at object-distances; the ' cubes ' on the right represent the opposite distortions following an increased interaxial—between either contraction in size apparently nearer or expansion in depth (' exaggerated depth ') at object distance. (*Crown Copyright photo.*)

' size ' assessed by convergence and, more importantly, by convergence-determined parallax, so the width and height of the scene—the ' spread ' of the scene in a plane at right angles to the line of sight such as that of the ' frontal plane ' set up in effect by the camera and subsequently transferred to the screen—

is also dependent upon an angular ' size ', again assessed by convergence, but this time by convergence at each of the two eyes individually. From this it is clear that the perspective of the reproduced scene is dependent upon the focal length of the camera lenses as well as upon that of the subsequent projector and of the viewing distance. To recreate, in correct perspective, the original scene for the viewing individual, it is essential that the width of the reproduced scene-image should be seen at the same distance as was the corresponding frontal plane, of the same width, seen by the eyes at the same distance originally. But if these conditions are not adhered to, it is deducible that *an increase in the distance beyond the correct viewing distance* will lead to a reproduced scene apparently further away; and, because the factors of parallax and convergence are still telling their original true story, the impression will be that of a scene of greater depth than the original. (Normally we associate objects apparently further away as being larger to suit. In the case under discussion however the apparent recession of the objects in the scene is accompanied by a reduction in their apparent size. Presumably the psycho-physiological reactions of the separate eyes, in this aspect of perspective, are the controlling factors and take charge in producing the illusion of diminished scene constituents.)

Convergence

Finally, there remains the effects of *variation* in binocular convergence. They are, in a sense, complementarily analogous to those of variations in perspective. It would be expected in the projection of a scene in which a frontal plane had been established at say the nearest contained object by convergence at that point that, whereas the reconstructed scene would appear normal at the right viewing distance if the projector objectives are toed-in to merge the front plane images exactly on the screen, an increased convergence would result in the whole scene moving nearer, accompanied by a compression and a decrease in the sense of depth. This is precisely what happens and the apparently nearer objects appear to become smaller. On the other hand if in projection the convergence is reduced and the rays splayed out further, it is to be expected and it happens that the

scene will apparently expand and recede, incorporated objects will appear to become larger as the back-to-front depth of the scene will increase. (A comparison between the effects here and those in the parallel recession case, when the viewed per-

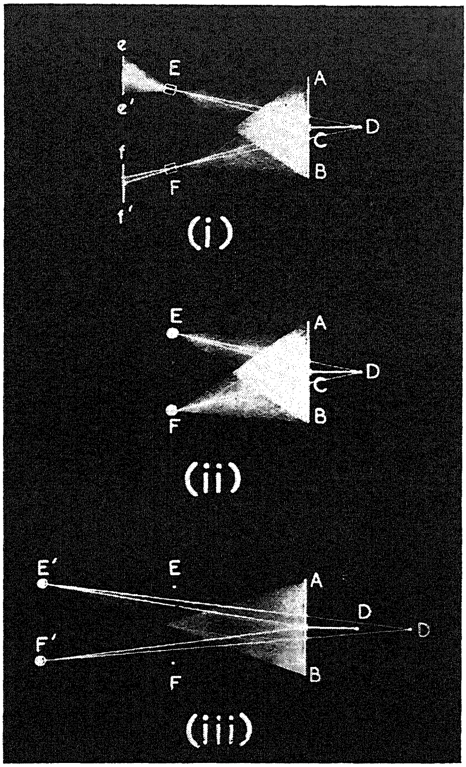

FIG. 10. *Exaggerated Depth Effect.* In (i) a line in depth *CD*, behind a frontal plane *AB* set up by two camera lenses *EF* converging on *C*, forms two short line images, on the respective films *ee'* and *ff'*, whose ends are indicated by a cross (image of *C*) and a dot (image of *D*). The intercepts of the corresponding rays concerned on the frontal plane are also indicated by a cross and dots. If projected effectively as taken, as in (ii), the cross and dots will appear on the screen in the same relative disposition and, to two eyes at *EF*, will appear to proceed from *CD*, of the same depth as in (i). To two eyes *E'F'*, however, situated behind this 'optimum viewing' position *EF* in (iii), the cross and dots will appear to proceed from a line of exaggerated length, stretching back behind the screen to *D'*. (*Crown Copyright.*)

spective was reduced, is interesting.) Precisely the same effects in both these cases of varied convergence will of course result when, the projector convergence being considered constant, the opposite change of convergence is applied at the camera when taking the pictures. Thus, for example a scene 'over-converged' when taken, will produce an illusion of a reproduced scene, further away, larger and of increased depth (the projector convergence being 'normal', i.e. toeing-in exactly at the screen.)

Interaxial Variations

It is now possible to comment upon any supposition that the effects of a decreased camera separation can be made good in projection. For, as has been seen, whereas a decreased separation can lead in projection to a reconstructed scene of less depth, an attempted compensation of the loss of depth by a decreased projector convergence can only lead to an exaggerated recession and enlargement; whilst an increase in convergence at the projector, although reducing and bringing nearer an enlarged and remoter image, would exaggeratedly decrease the stereoscopic depth of the reconstructed scene.

'Natural Vision' Re-Presentation

On analysis therefore, there is no alternative if an entirely *natural* stereoscopic reproduction is in view, but that of facsimile reproduction of each and all of the geometrical scene factors operative at the time and place of taking, these being an appropriate 'monocular' perspective, together with 'interocular' convergence and parallax.

Minor Factors

We have seen that disparate images, convergence, accommodation, perspective, relative motion, colour light-and-shade and atmosphere were all contributing factors to the stereo-scopic illusion. Of these the first four merited special attention; the remainder are minor factors of a fairly obvious contributory nature. The underlying conviction to which throughout our findings have been hardening is that, only by reproducing in all its aspects the precise circumstances of direct vision attending

FIG. 11. *Distortion in Reproduction.* 1. The figure shows a stereo-pair of a medium close-up, shot with lenses at interocular spacing and so reproduced that it is correctly viewed for perspective with a stereoscope of $3\frac{3}{4}$ in. focal length. So viewed the depth and perspective appear entirely natural.

FIG. 12. *Distortion in Reproduction.* 2. The figure shows the same subject as Fig. 11 shot under the same conditions, except that the camera lens spacing has been reduced to roughly a half, and thereby the parallax. Viewed with the same stereoscope as before, the perspective is correct but the depth of the subject appears flat and the individual scene details show a 'cardboard' effect, owing to the decreased parallax. Viewed by a stereoscope of longer focal length in an attempt to discount the loss of parallax, the result is still flat. (Compare with Fig. 14.)

FIG. 13. *Distortion in Reproduction.* 3. The figure shows the same subject as Fig. 11 taken from twice as far away but with normal interocular lens spacing. This gives the same angles subtended by scene details at the camera as obtains in Fig. 12. Viewed with the same stereoscope as before, depth and perspective incidentally appear entirely natural *for this distance.*

FIG. 14. *Distortion in Reproduction.* 4. The figure is Fig. 13 enlarged and suitably remounted to simulate the aspect seen from the viewpoint of Fig. 11. Examined with the same stereoscope as before, the result provides an unnatural balance between the perspective appropriate to nearby and the parallax of distance. Looked at, however, with a stereoscope of twice the focal length as before or, if you have the knack, *directly* with the eyes, the result is natural, as the perspective has now been put right for distance and the parallax is right anyway.

upon the perception of a given scene, is it possible subsequently to recreate in its stereoscopic representation a satisfying, convincing and accurate illusion.

Major Factors

Deficiencies in one of the major factors contributing to the stereoscopic representation of the original scene cannot ideally be made good by an over emphasis of another. When viewing a given scene the brain forms, from the contributing factors and in the light of long experience, an awareness of the scene in depth. The contributions from each factor are unique for that scene under the conditions obtaining at the moment of viewing. If the stereoscopic reproduction represents all those factors of viewing precisely, it will re-create the original scene as a perfect illusion. To particularize, it is necessary (dealing only with the essential major factors) that: the images presented to the eyes on the projection screen shall be duplicates of those disparate images of the original view seen by the eyes and which are due to the different parallax associated with each; that the convergence angle presented to the eyes by the object of major interest at its apparent distance in the stereoscopic reconstruction shall be the same as the toe-in angle the eyes took up viewing the original and which the brain associates with viewing at this distance; that the angular size of the images in the screen shall be the same as that subtended to the eyes in the original scene at the stance from which the pictures were recorded, that is to say, with identical perspectives; and finally, for practically indistinguishable results as between reproduction and original, that the focusing accommodation of the eyes in viewing, necessarily at the plane of the screen, should be the same as that adopted by the eyes in viewing the foreground object of major interest in the original scene.

On the basis of such premises, it follows that a stereoscopic reproduction of a scene which depends upon disparate images which have been photographed with parallaxes associated with view-points separated by a distance apart substantially different from that of the average human interocular cannot, in any circumstances of viewing, instil completely the desired illusion of being the veritable scene itself.

CHAPTER III

PROJECTION REQUIREMENTS AND METHODS

We have seen in the previous chapters what the factors are that can contribute to the appreciation of three dimensional space when a scene is viewed by the eyes in Nature, and how these same factors came into play, in viewing the reconstructed scene on the stereo screen. Let us now examine the few simple geometrical requirements of 'normal' stereo representation and see by what basic projection methods these requirements can be met.

GEOMETRICAL REQUIREMENTS OF PROJECTION

The inescapable geometrical requirements of a satisfying projection, whatever the viewing-aids, projection methods and individual projecion systems may be that are employed, are four in number. Firstly, let us state these, and afterwards examine how they are to be achieved. They are: (i) the prevention of too severe a departure from the convergence accommodation ratios that we are accustomed to in normal vision; (ii) the prevention of 'divergence', that is to say, a splay-out of the 'infinity points'—to be explained in a moment; (iii) the establishment on the screen, or rather 'in' the screen, of a definite 'window', with well-defined and merging side-borders, *through* which the three-dimensional reconstructed scene is more often than not to be viewed; and (iv) the avoidance of too marked a departure, in the viewed image, from that natural depth which is associated with the original scene. Let us take these four requirements in order and see what they imply.

Convergence/Accommodation Ratio

The requirement in (i) could always be met by ensuring that no object, however near to the camera when the film was being taken, was projected in such a way that it appeared as though located in front of the screen. For, as we have already seen earlier on, the eyes when looking at a real object are used to a convergence of the two eyes and a focussing accommodation to suit, both being appropriate to the particular distance of the object. Or put more shortly, there is a particular convergence/accommodation ratio appropriate to every particular object-distance. When we gaze at our stereo movie screen and watch the images projected on to its surface we have, willy-nilly, to accommodate our eyes at the screen to focus sharply the images displayed upon it. The be-all and end-all of our projection, however, is to create the illusion, by the projection of disparate images and by the different angles of convergence of the constituent objects in these two images so set up, that these object images are at varying distances from us; either in front of, at the screen, or behind it. Only those images apparently within the plane of the screen will have the same convergence/accommodation ratio that the corresponding objects in the original scene had when initially viewed and taken by the camera. It is only therefore for such objects that the stereoscopic illusion can be absolutely complete. Fortunately the brain seems to react kindly to object-images located apparently behind the screen, although the eyes are focussed on the screen and the convergence/accommodation ratio is less than it should be. But for object-images in front of the screen, there is a limit to what the normal brain can stand. It has, however, been found from observation in recent public exhibitions of 3-D films that the normal person can view without marked discomfort an object-image apparently up to at least some half-way between himself and the screen and, for those in the rearmost seats, considerably nearer than that. All doubts as to the psychological reaction of the audience to front-of-screen images could be resolved, however, if we set out, when taking the film and when subsequently projecting it, to ensure that no object-image was projected in front of the screen at all. We shall see shortly how this can be accomplished and,

as a standard guiding rule at least where small screens only are concerned, it is well worth the achievement. For nothing can be more natural than the illusion that the screen is a window through which we are looking, and is therefore one beyond

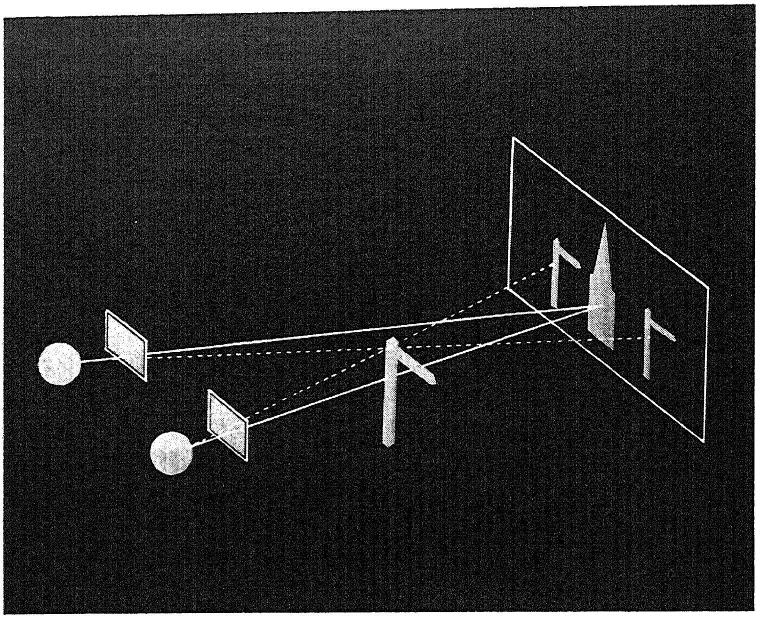

FIG. 15. *Convergence/Accommodation in Projection Viewing*. The Disparate Images recorded in the camera of a near sign-post and a distant steeple have been projected on the screen so that the two steeple images are superimposed in the plane of the screen. Through polaroid glasses each eye sees its own displaced sign-post image by converging rays and imagines the sign-post in front of the screen. Because the eyes are focussed at the screen, the sign-post, if appearing closer than, say, half-way from the screen to viewer, will have an abnormal amount of associated convergence and cause strained viewing.

which all objects are expected to be seen. Furthermore, it will be normal when taking the film, to concentrate upon and converge our lenses upon the nearest close-up, usually the major object of interest anyway. Having made such a rule and arranged to arrive at such a result automatically, the rule may be broken in certain special circumstances. For example, a branch of a

flowering bush, a pointing hand and arm, or a ball coming out of the screen may all, as a special effect, be projected into the auditorium provided the particular object does not break into the margins of the picture. Such stunts can be very spectacular, but should not be employed too often. Apart from these special effects, however, it will be found that in large-scale practice, especially where very wide screens are being employed, that there may be no alternative to bringing images of close-ups that must be included forward of the screen if the depth of the particular scene is such that not to do so would inevitably lead to divergence of the infinity points or even divergence of background objects which are considerably nearer, in such a manner as is to be described in a moment. Apart from the consideration that the consequent abnormality in the convergence/accommodation ratio must not in such circumstances become excessive, there is another facet of the manœuvre that must also be taken into account. As already mentioned, it is normally important to avoid breaking the margin of the window, especially the side-margins, by the images of close-ups which are in appearance nearer. For, in this event, a conflict of evidence presented to it has to be resolved by the brain in deciding what to make of a pair of near images in close proximity to the boundaries of the picture when the margin of the window is clear of one of the pair of stereoscopic images but totally obscures the other. This unnatural effect may be alleviated to some extent by avoiding marginal *static* objects in taking the scene, or at least in refraining from ' holding ' them for any appreciable length of time. Much more, however, may be done by availing ourselves of an artifice due to Spottiswoode whereby the image of a ' subsidiary ' window is set up in appearance in front of any image of a close-up that is to figure in the scene by ' overprinting ' on the film during processing the boundary margins of an artificial window to overlap and obscure those of the actual window recorded by convergence means in taking. In effect, a subsidiary window so produced, ' floats ' in free space in the auditorium between the screen and each member of the audience wherever seated, all images of close-ups being seen through it without any visual confusion or mental conflict arising if, when, and where the two happen to coincide.

Divergent Infinity Points

The second important requirement (ii) in projection sets out to secure that in no circumstances do the eyes in viewing splay outwards. This could happen in the following circumstances. Imagine that a scene is being shot in which we have the close-up

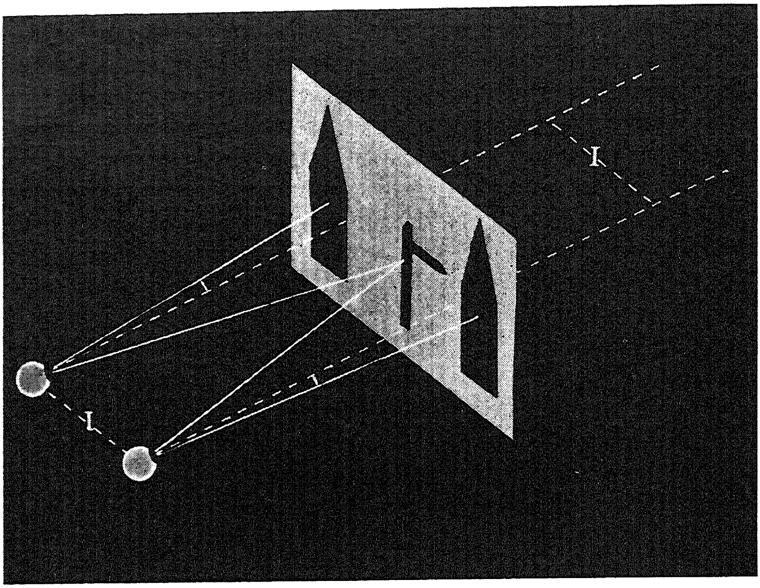

FIG. 16. *Infinity Points.* If the Disparate Images recorded in the camera of a near sign-post and a distant steeple are projected on the screen so that the two sign-post images are superimposed in the plane of the screen, the two steeple images may be displaced to the extent that two eyes seeing these separately may have to splay out, setting up eye-strain.

of major interest in the foreground and situated, to simplify the explanation, in the centre of the field. If a particular taking/projecting method is adopted, from amongst those to be described later, in which the camera lenses converge upon or ' toe-in ' at this close-up, there will be two points some 2½ in. apart on the distant horizon or background, which are ' opposite ' the centres of the two lenses and from which two parallel rays would pass through the centres of the lenses to the centres

of the two images of the pair formed in the camera. These points at 'infinity' are called the 'infinity points' of the two lenses. Between these rays proceeding from the infinity points to the lenses, and those from the lenses to the close-up, there will be subtended some angle (equal on each side, of course, in this particular symmetrical case chosen) whose magnitude depends on the distance of the close-up. Should the projector lens used in subsequent projection be equal in focal length to the camera lenses, the geometrical set-up will be precisely as in taking, as the angles concerned are identical. The two rays to the infinity points will still therefore be parallel and the infinity points consequently still $2\frac{1}{2}$ in. apart. To a viewing member of the audience wherever placed, in these special conditions of projection, the left eye will see its appropriate left-eye infinity point, and the right eye its right-eye infinity point, each by parallel rays, since the infinity points are at the same distance apart on the screen as the eyes are, and there can be in consequence no splay-out of the eyes. Similarly no divergence of the eyes can take place if two projector lenses of any focal length are set up to give 'parallel projection', that is to say, projection in parallel directions of the two infinity-point images. There are, however, other basic methods of projection which, as will be seen later, can lead to divergence of infinity points if certain precautions are not observed.

Margins

The third requirement (iii) is that the margins of the left and right-eyed pictures thrown on the screen should be merged into coincidence to form the *window* through which the stereoscopic reconstruction is apparently to be viewed. If we do otherwise, there will be at each side of the (combined) picture on the screen a vertical strip appropriate to one eye only and thus incapable of displaying stereoscopic depth. Such strips are distracting and can militate severely against a completely satisfying overall sensation of depth elsewhere apparent. In such circumstances, a palliative can be adopted by masking out the offending side strips, but only at the expense of picture width. Width, however, in a stereo picture is all important; the wider the horizontal sweep of stereo vision that is possible, the more convincing the

illusion will be. Basic methods of projection are available, as will be seen shortly, which can secure a well-defined ' window ' framing without any loss of valuable picture width.

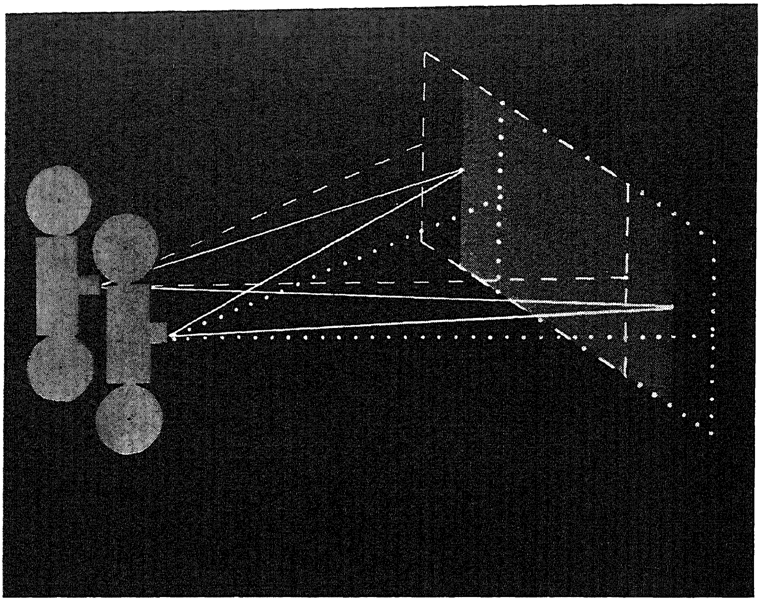

FIG. 17. *Centering and Merging Margins.* In parallel projection (or in taking with parallel cameras) the two projected (or taken) frames will overlap (shown dotted), leading to non-coincident centres and wasted non-superimposed, and therefore non-stereoscopic margins. If the projectors (or cameras) were toed-in or converged, the two left- and right-eye images would become coincident, centres would coincide and wasted margins would become non-existent.

Natural Spatial Depth

The final major requirement (iv) is that the *depth* of the projected reconstructed scene should be ' natural ', neither more nor less pronounced than in nature. In the portrayal of the human head in a close-up for example, too much depth can lead to an aspect of exaggerated aquilinity, or the reverse to one suggestive of a moon-face. All the basic methods of projection are, if improperly applied or viewed, susceptible in their results to

such departures from the realistic. The origin of these anomalies in depth portrayal lies fundamentally, as we have seen, in the improper association of the three factors of Perspective, Convergence and Parallax.

BASIC METHODS OF PROJECTION

Now that the four requirements of successful stereo projection have been recited and examined, the question naturally arises as to what the various basic *methods* of projection may be that conform to the geometrical requirements and to what extent each fulfills some or all of these. The methods are merely in fact only various modifications in the situation or alignment of the camera lenses and of the projector lenses. What are these alternatives? They are found to lie in: a decreased separation of the camera lenses; an increased separation of the projector objectives; a converging camera lens system together with a diverging projector objective system; or a combination of one or more of these. If all are examined systematically in turn it will be found possible to predict from first principles to what extent they will achieve the desired aim of fulfilling those first three of the four projection requirements that are possible by projection methods if we leave out for the moment considerations of the results of deliberate deviations from the reproduction of ' natural ' perspective, convergence and parallax.

Parallel Projection

As we have seen, the straightforward method of taking and projection, in which the camera lenses and the projector objectives are lined up ' parallel '—that is, directly in front of the centre of the appropriate left or right film image in each case—makes certain that in no circumstances will there be a divergence of infinity points (ii). On the other hand, for near close-ups, too severe an increase in the convergence/accommodation ratio over that proper to normal vision can occur (i), expecially when the size of the screen has been increased to cater for the bigger audience. This drawback could be discounted by seating the audience further back, but this would nullify the purpose of the larger screen and would lead also to a stereo reproduction of

unnaturally increased depth. With parallel projection too, the formation of merging side-margins and the establishment of a window (iii) is not possible, and picture-width is lost.

Reduced Interaxial

Taking now the alternatives to parallel projection, the first of these is the expedient of reducing the spacing between the two camera lens-axes, still, however, maintained parallel, from the standard interocular distance of 66 mm. to something less, and subsequently projecting ' parallel '. (There is in any case an initial disadvantage in this method in that it can involve com-

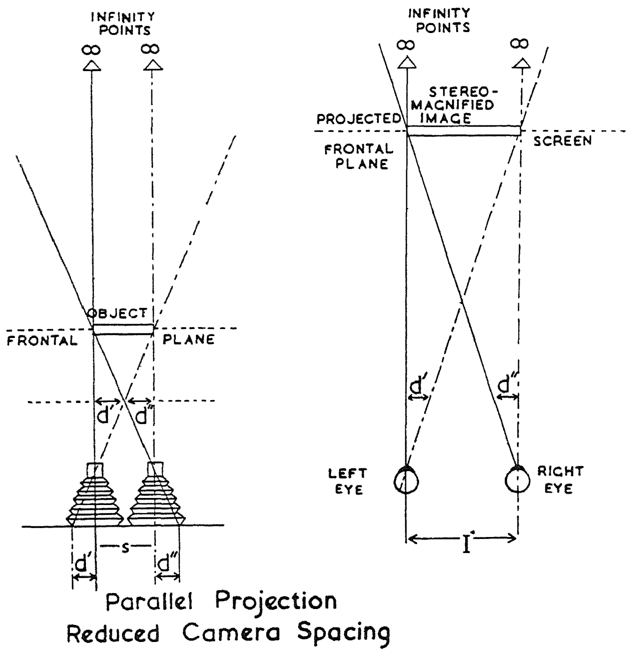

FIG. 18. In a method of overcoming the excessive convergence/accommodation ratio set up in parallel projection of near objects, the taking cameras may be closer spaced (*s*) than the ' interocular ' distance (I), and subsequently projected parallel and viewed at interocular. The near object, which would otherwise have been seen with unnatural convergence in front of the screen at which the eyes are focused (accommodated), now sees this as being within, say, the plane of the screen. ' Stereo-magnification ' of the image will be seen to have occurred.

plicated and expensive ciné-camera design and equipment.) As in the case of parallel projection, there is no divergence of infinity points (iii); but in this case we have now overcome the increase in the convergence/accommodation ratio for close-ups (i) because we have, by taking the picture with two (parallel) axes close together and then widening apart these axes at the projector, enlarged in effect the view; and this therefore is apparently seen further away, as though the view had been pushed back through the screen. A close-up, seen apparently at a greater distance, is now interpreted as being larger than life—a phenomenon known as stereo-magnification or ‘ giantism ’. If, in combating the giantism effect the two projectors are converged, since the two disparate images concerned—immutably recorded on the film in the camera—are those associated with an ‘ interocular ’ of less than normal, the projected stereo reproduction must be either ‘ keystone ’ distorted in depth or appear ‘ flat ’ from a lack of its proper depth, whatever the convergence. In this method the establishment of a proper window and the prevention of loss of picture width (iii) is not possible without both camera and projector convergence.

Divergent or Spaced Projector Lens-Axes

In a (theoretical) second alternative to parallel projection, where freedom is being sought from too large an increase in the convergence/accommodation ratio over normal (i), we could of course either *diverge* the projector lens axes or *space* these wider apart whilst still maintaining them parallel; but in either case, obviously only at the expense of introducing some divergence of infinity points (ii). In either event too, the establishment of a window (iii) is clearly not possible, and the loss in picture width through overlapping side-margins is even more pronounced than in parallel projection.

Convergent Camera and Projector Lens-Axes

The remaining two important alternatives each give substantially the same results as each other, and each is based upon *convergence* of the camera lenses (upon say the nearest close-up of major interest) and upon a subsequent correspondingly appropriate convergence of the projector objectives (to give merging

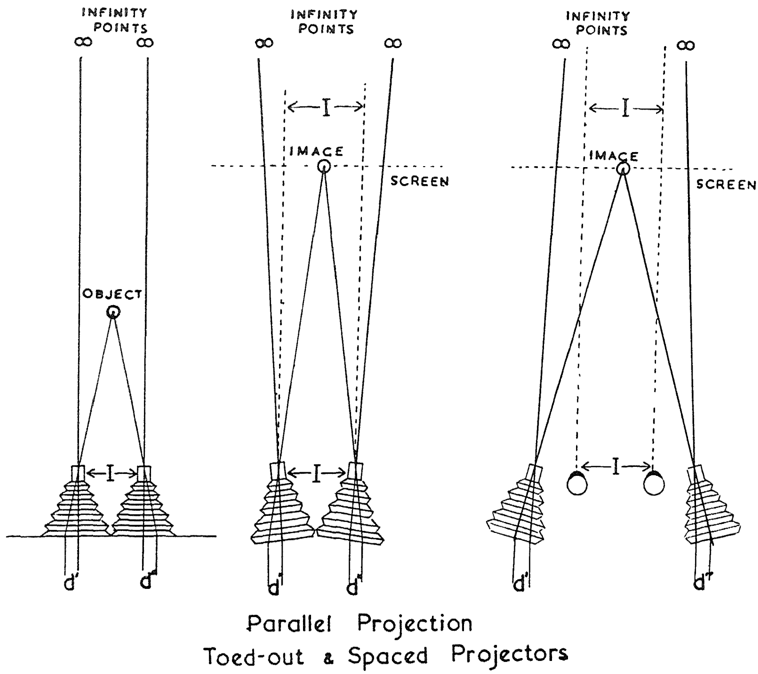

FIG. 19. As a palliative in overcoming the unnatural convergence/accommodation ratio set up in parallel projection of near objects, the projectors may be 'toed-out' thus locating the near-object image, say, in the plane of the screen, but at the expense of 'Diverged infinity points'; or the projectors may be spaced wider than 'interocular' to give the same result. Here a slight projector 'toe-in' will overcome diverged infinity points.

of the left and right frame margins at the screen 'window'). In the first of these methods the camera lens convergence is achieved by an inward *shift* horizontally towards each other of the lenses. A precise analogue to the movement and to the results lies in the 'cross front' of the ordinary still 'field' or 'commercial' camera, if one imagines two of these cameras side-by-side, the cross movements of the two lenses, with respect to the fixed films, being arranged to be equally towards each other. As in the analogue, the method is free from lateral keystone distortion, but it is a difficult and expensive one to incorporate in either paired ciné cameras or in a single ciné camera adapted to take both left and right pictures on the one

film. In the second of the two methods, convergence of the two lens axes is very simply brought about by a mere *swing* of the two cameras as a whole inwards. Whether carried out in fact with two cameras, or by only one where the in-swinging is accomplished by a beam-splitter, the method is simple and inexpensively incorporated. It is not, however, a method which gives entire freedom from distortion in the resulting images; but such distortions are far from serious, and can be made innocuous.

These two converging methods can in the first place completely

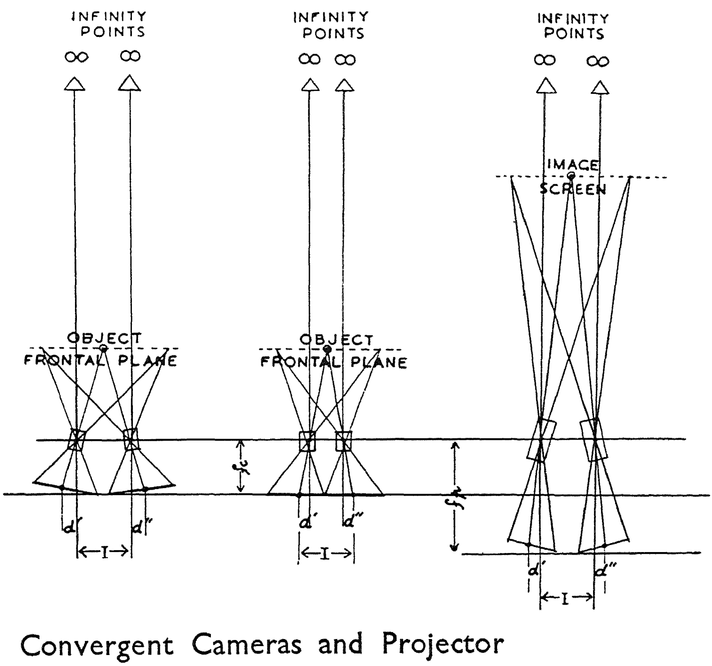

FIG. 20. The two pitfalls of stereo-projection—an excessive ‘ convergence/accommodation ’ ratio and ‘ divergent infinity points ’—can be overcome by converging both camera and projector. When shooting, the cameras as a unit may be converged on the nearest object to place its image in the centre of each frame, or the lenses may be moved laterally towards each other to the same end. In projection, the projectors are converged to put the image of the nearest object in the plane of the screen. Infinity points will not diverge if the formula in the text has been applied.

satisfy the requirement (iii); for, if the lens axes converge for example on the nearest close-up, the recorded image frames will be in effect convergent in the plane of the close-up, setting up our ' taking ' window in effect in a plane placed where we subsequently intend to look through it, i.e. at the screen, where the projector objectives will subsequently be toed-in to merge this frontal plane and hence the close-up. There will thus be no marginal loss of the all-important picture width, either in taking or in projection.

In so far as the remaining requirements (i) and (ii) are concerned, the extent to which these are satisfied will need more detailed examination. Before carrying this out, let it be briefly stated that in some circumstances, usually most, these two methods can also satisfy completely requirements (i) and (ii). In the remaining circumstances, either (i) is completely satisfied only at the partial expense of (ii), or *vice versa*; but the choice of either alternative is always an open one; or the circumstances can be deliberately modified or evaded to satisfy both requirements.

To examine these points in more detail, let us again imagine as we did earlier on, the situation in which we have two camera lens axes lined up parallel on to the infinity points of each. The two rays from the two infinity points both strike the centres (horizontally) of their respective films after passing through the lenses. If now, by swinging the cameras inwards, or by an inward shift of the lenses, we converge the lens axes on to a close-up, it will be the images of the close-up which now occupy the centres laterally of the films, and the images of the infinity points will have been displaced away from the centres inwardly. The amount of this inward displacement obviously depends on the width of the film, the focal-length of the camera lens, and the distance of the close-up. If we were to project these films so taken with projector objectives of the same focal length on to a screen at the same distance as the close-up was, we should be reconstructing the original conditions exactly; the close-up image would be on the screen, the infinity points would be at camera-lens spacing (i.e. at interocular) on the screen; and the requirements (ii) and (iii) would thus be met. Usually and preferably, however, projector lenses have a focal length of some

two or three times those of the camera. Let us suppose they are twice. If the distance of the screen from the projector is also twice that of the original close-up from the camera, the geometrical pattern is precisely re-established and the projected infinity point rays to the screen will not diverge (ii) when the close-up is merged at the screen (iii). If, however, the screen is further away than this, we shall get divergence. For a given screen distance (or width—a more convenient 'condition') there is obviously a minimum distance to which we can safely converge when taking close-ups, whilst yet fulfilling the requirements (i) and (ii).

THE FORMULÆ

These basic requirements of projection, in terms of lens displacement and convergence, should now be mathematically examined.

Infinity Included

In Fig. 21 (i), C represents the optical centre of one of a pair of the camera lenses of focal length f_c, EF the film and CE, CF the boundary rays of the effective angle of view. The line CA represents the direction of the infinity point of C, whilst B represents the centre of the scene being taken; a chosen included object whether close-up '*CU*', at middle-distance '*MD*', or a

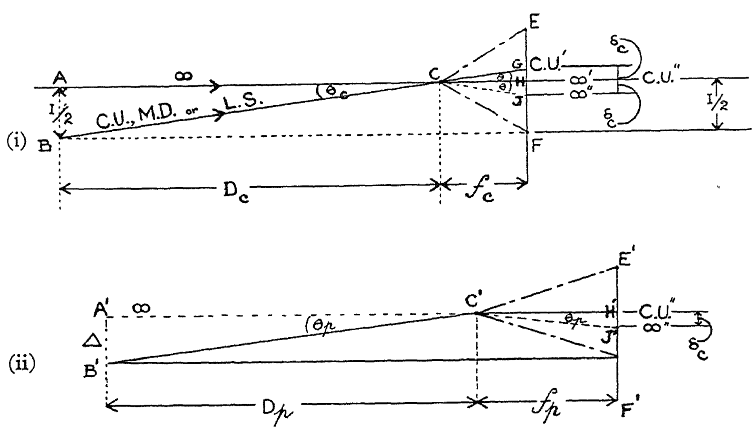

FIG. 21.

long shot '*LS*', being taken indiscriminately at a 'range' or distance of D_c. *A* and *B*, separated by a distance of $I_{c/2}$, half the lens-separation, lie in the horizontal plane. (In the case of rotating beam-splitting attachments described in a later chapter, *EF* is taken as vertical, a 90° rotation being assumed to have taken place at *C*. The deductions that follow apply equally nevertheless to all systems.)

With no convergence 'toe-in' applied, i.e. for a 'parallel' setting, the parallel-ray *AC* emanating from the infinity point of the lens *C* forms an image, '∞'', of *A* at *H*, whilst the ray *BC* from an object in the centre of the scene at *B*, forms an image, 'CU'', at *G*, the distance on the film between *GH* being represented by δ_c. The camera, half-camera or half-attachment as the case may be can be 'swung' upwards by δ_c so that, in effect, the parallel ray *AC* now forms an image, '∞''' at *J*, where $HJ = \delta_c$, the ray *BC* now forming an image 'CU''' at *H*, the centre of the film; thus centring the whole width of the taken scene at *B*, which is to be the centre of the 'frontal plane' and hence of the 'window' through which the stereoscopic representation of the scene is subsequently to be viewed, to record it on the film and centre it at *H*. Whether this centring convergence, or the equivalent lens shift, to establish a frontal plane in taking is applied or not, the following analysis remains applicable in either case.

The expression that arises following these dispositions is by similar triangles:

$$\delta_c = \frac{f_c}{D_c}\frac{I_c}{2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (a)$$

In Fig. 21 (ii), the subsequent projection case is depicted, where the two converged rays already discussed are reversed, symbols of corresponding points to the camera analogue being the same but shown with 'dashes', whilst the distance of projection throw D_p, and the focal length of the projector objective f_p, are not necessarily or usually the same as before. The requirement is also similar, that the image CU'' at H' is to be thrown on to B' the centre of the screen, thus securing that the recorded frontal plane $E'F'$ shall become the window and occupy the full width of the screen. The infinity point image

∞'' at J' is projected on the screen at A', at a distance of $\triangle$ from B', the centre of the screen. To comply with the further requirement that the infinity points shall not cause divergence of the viewing eyes, i.e. that they shall not be separated on the screen by more than the interocular distance I, it is necessary to find the condition whereby $\triangle = I/2$. By similar triangles:

$$\triangle = \delta_c \frac{D_p}{f_p}; \text{ and substituting for } \delta_c \text{ from } (a)$$

$$\triangle = \frac{f_c}{D_c} \cdot \frac{D_p}{f_p} \cdot \frac{I_c}{2} \quad . \quad . \quad . \quad . \quad . \quad (b); \text{ and if}$$

$$\triangle = I/2 \text{ (requirement), then from } (b)$$

$$D_c = D_p \cdot \frac{f_c}{f_p} \cdot \frac{I_c}{I} \quad . \quad . \quad . \quad . \quad . \quad (c).$$

But if w_s is the effective width of the screen, and w_f the width of the film frame, D_p and f_p being the corresponding distances of subtention through the projector objective; then again from similar triangles:

$$\frac{D_p}{f_p} = \frac{w_s}{w_f}, \text{ and eliminating } D_p \text{ and } f_p \text{ from } (c)$$

$$D_c = \frac{w_s}{w_f} \cdot f_c \cdot \frac{I_c}{I}, \quad . \quad . \quad . \quad . \quad . \quad (1), \text{ and if the}$$

ratio of the actual camera-lens (reduced, for example) interaxial distance, I_c, to the interocular distance, I, is taken as i, the 'interaxial' factor, and the ratio w_s/w_f is substituted by its equivalent 'Magnification' factor, M, then:

$$D_c = M f_c i \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{I.}$$

Infinity Excluded

The equation (1) gives the distance D_c of the frontal plane, and hence of the nearest close-up that can be taken for subsequent projection on a screen of width w_s, with a camera lens of focal length f_c working on an effective film-width of w_f, if the side margins of the two superimposed half-pictures are to merge on the screen and there is yet to be no divergence of the projected images of infinity points.

Nearer close-ups can be taken if the distance of the furthest object included in the scene is not situated at infinity. For, if in Fig. 22 two toed in rays are considered, one (from the

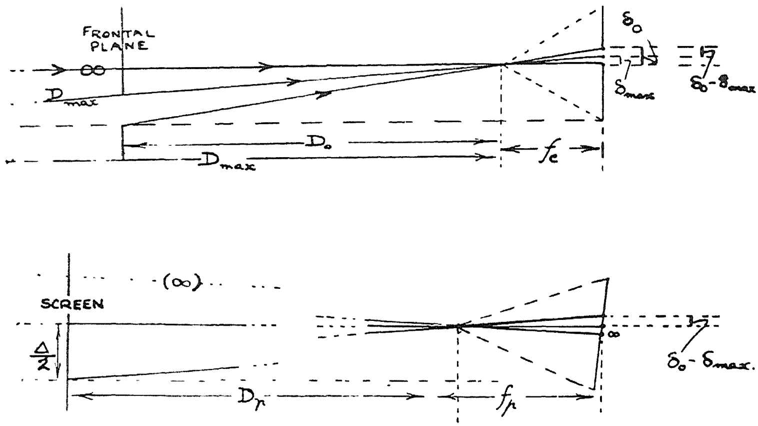

FIG. 22.

nearest close-up desired) emanating from a distance D_o, and the other (consequent furthest object) from a distance D_{max}, the corresponding distances from the centre of the film-frame at which images of central points of these two objects will be recorded, would be respectively from equation (*a*):

$$\delta_o = \frac{f_c}{D_o}\left(\frac{I_c}{2}\right), \text{ and } \delta_{max} = \frac{f_c}{D_{max}}\left(\frac{I_c}{2}\right).$$

If now, as it will be in subsequent projection, the furthest object ray be swung parallel to take the place of the now-missing parallel ray from the ' infinity point ', the two object rays will emanate from the film in the projector gate from two points at a distance on the film of $\delta_o - \delta_{max}$ from each other and, having passed through the optical centre of the objective of focal length f_p, will be projected on the screen at a distance of D_p, to give a lateral displacement on the screen between the two object centre-point images of $\Delta/_2$, which remains to be determined. From the two similar triangles implicit:

$$\Delta = 2\frac{D_p}{f_p}(\delta_o - \delta_{max}),$$

and remembering that $D_p/f_p = w_s/w_f$ as obtained earlier,

$$\triangle = 2\frac{w_s}{w_f}(\delta_o - \delta_{max}).$$

If now the values of δ_o and δ_{max} obtained above at (*d*) be substituted, it follows that:

$$\triangle = 2\frac{w_s}{w_f} \cdot f_c \cdot \frac{I_c}{2}\left(\frac{1}{D_o} - \frac{1}{D_{max}}\right),$$ which reduces to

$$D_{max} = D_o \frac{w_s}{w_f} f_c I_c \Big/ \frac{w_s}{w_f} f_c I_c - \triangle D_o,$$ and if $\triangle$ be put

equal to I, the requirement for non-divergence,

$$D_{max} = D_o \frac{w_s}{w_f} f_c \Big/ \frac{w_s}{w_f} \cdot f_c - D_o \quad . \quad . \quad . \quad . \quad . \quad (2),$$

$$\text{i.e. } D_{max} = \frac{D_o M f_c i}{M f_c i - D_o} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 2$$

where, as in equation (1), the interaxial factor i is inserted and w_s/w_f is substituted by the Magnification factor M.

This formula gives the maximum depth of scene that can be employed between a frontal plane at distance D_o from the camera lens and the furthest object that can be included (at a distance D_{max}).

Alternatively this equation can be used to derive the distance of the furthest object, D_{max}, that can be included in a scene, for various close-up distances D_o, and for various camera lenses, when using a larger screen.

(If, in this equation (2) we put the expression Mf_ci equal to D_o—i.e. equal to D_c, from equation (1)—the denominator becomes equal to zero, the whole expression on the right-hand side of the equality sign then becomes equal to infinity, and therefore D_{max} becomes equal to D_∞; which it should in these circumstances if equation (1) is true. That it does so shows that, not only is equation (1) true and compatible, but that equation (1) is a special case of equation (2) when objects at infinity (D_∞) are to be included. Equation (2) is therefore an *all inclusive* 'general' equation, as it is called, which is universally applicable, in and for all circumstances.)

This formula, as well as the previous one, using different symbols and derived in a different way, was first given together with many other variants by Professor Rule in his classic paper 'The Geometry of Stereoscopic Projection' in 1941.

The statement: 'maximum depth of scene', implicit in and given by this formula, presupposes that the nearest close-up included will *not* be projected in front of the 'frontal plane', photographed at distance D_o, which will and must appear in the plane of the screen when projected. Nearer objects can still, however be included, thus increasing the maximum depth of scene that may be included, if these are to appear in front of the screen. In this event we can substitute for D_o, the old minimum distance, D, the new minimum distance, where:

$$D = D_{o/n},$$

in which 'n' can be regarded as a 'proximity' factor.

With this substitution, the general equation (2) becomes:

$$D_{\max} = \frac{nD\,Mf_c i}{Mf_c i - nD} \qquad \ldots\ldots \quad (3)$$

and is now truly general as it covers all possible dispositions in the gamut of photographed objects from lens to infinity.

CHAPTER IV

VIEWING AIDS

WE are now in a position to review in turn what the practical embodiments of these basic projection methods are that we have considered in Chapter III. These embodiments, or *systems* as we might with more convenience call them, all employ some particular device or artifice in taking and projecting the pictures, whilst yet fulfilling the requirements of, and conforming to one or other of the basic patterns of projection. In many cases, however, these systems are free to employ one or more of a choice of necessary *viewing aids* which can discriminate, as between the left and right viewing eyes, the two disparate images: an essential function in stereoscopic viewing. It is first necessary then to review the various forms that these viewing aids can take before particularizing on the various stereoscopic systems in a later chapter. But first, it is expedient to describe two or three systems which embody their own particular and specific ' eye-selector ' mechanisms basically inherent in the projection concept as a whole.

THE ' ROVING EYE '

Such systems, it will be found, differ from the remainder in having a different approach in their type of presentation of the stereoscopic illusion. What they attempt to do is to present on the screen an ideal reconstruction of Nature as it can be viewed by a pair of roving eyes, instead of that type presented by the others where the reconstuction is only that of what a fixed pair of eyes would have seen. This ideal type of solution, the solution of the future—albeit remote—is an *integrating* one. It is based on the fact that in nature rays of reflected light emanate from all objects in all directions and that they are all pervasive. A single

'pin-point' eye, placed at a particular point in front of a scene, receives a specific bunch of rays from every object within the visible scene which is entirely different, ray-by-ray, from the bunch it would receive if it were moved by an infinitesimal distance to one side or the other. In such a conception, in which each of the two eyes receives its individual bunch of rays uniquely associated with the precise location of each eye, we cannot speak solely of one set of rays as constituting the 'left-eye' view and another set the 'right-eye'. For a slight shift of the head by $2\frac{1}{2}$ in. to the left, for example, would result in the right eye now seeing what the left-eye previously saw; whilst the left-eye has in the meantime picked up an entirely new set of rays. In consequence, the *integral* or integrating type of stereo projection essays to reproduce, at every possible position of an eye within the auditorium, a bunch of rays unique to each and every one of these positions, and all identical with those of the corresponding eye positions situated in front of the original scene viewed, that it is sought to reproduce.

Integrating Screens

The 'integral' type of stereo projection and viewing can best be understood by a brief description of how one of them—the *parallax stereogram* system—has developed from the use of a grating as an elementary form of viewing aid but which, owing to its extremely limited practicability, has now little other than historical interest. This was a proposal, made independently by Jacobson and Berthier at the close of the last century, and later thrown into a practical form by F. E. Ives of U.S.A. in 1903 and by Estenave of France in 1906, whereby two left- and right-eye pictures seen from a fixed stance were to be photographed through a vertical grating in front of the film the width of whose apertures was equal to that of the bars. If the scene be taken through a camera lens of larger diameter masked to be effective only through two small apertures spaced at interocular distance apart, the two left- and right-eye scene images so produced are split up into interlaced vertical strips by the grating, as the pairs of image-strips formed through the grating apertures occupy the grating-bar 'shadows' of each other, if the distances of lens aperture-to-grating and of grating-

to-film have been correctly determined. Such a film projected on to a screen with a similar grating in front would, when viewed by a pair of eyes at a particular distance, be seen stereoscopically as each eye would see only the component strips appropriate to its own proper picture through the gaps in the grating, whereas the bars obscure those of the other. The

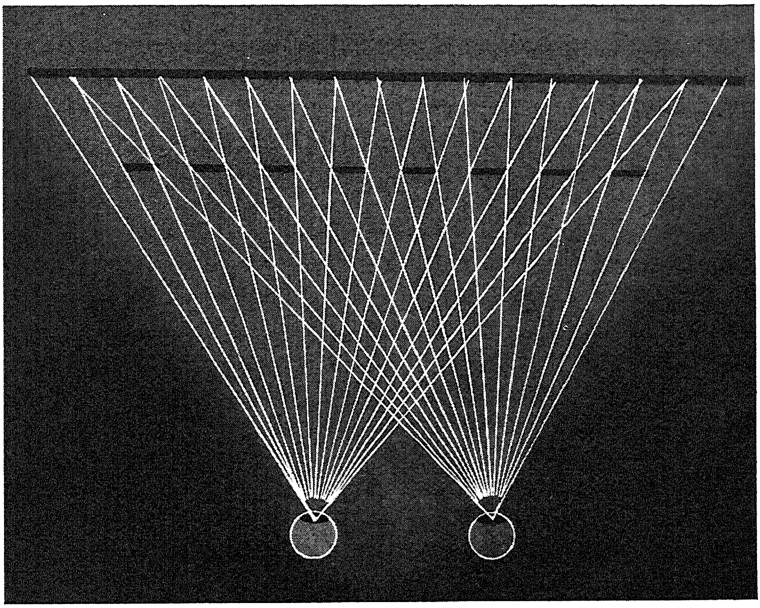

FIG. 23. '*Grid*' (*Two-picture*) *Projection*. A left- and a right-eye picture are taken through a grid, which divides them into narrow vertical strips placed alternately side by side. When projected and viewed through a similar grid, the left eye sees only the left-eye strips and the right eye only the right-eye strips.

limitations of this method lie in the fact that there is only one correct distance of viewing, and sideways motion of the head reverses a correct or 'orthoscopic' stereoscopic effect into a 'pseudoscopic' one in which distant objects appear to be near, and near ones far.

Apart from this apparently fundamental limitation to the grid system in general, there are other drawbacks associated with its early elementary forms which later inventors have

sought to overcome with varying success but in no case, as yet, to the extent of achieving large scale commercial exploitation. These drawbacks include: the loss of half the picture strip-elements in each of the left- and right-eye pictures due to their absorption by the grid bars; a loss of available light of at least 50 per cent. for similar reasons; and the effects of diffraction at the grid-bar edges together with the closely associated difficulty in eliminating the grid pattern superimposed upon the picture and in avoiding 'shot-silk' phenomena. The first of these was overcome to a large extent by screens of the lenticular type, consisting of a large number of parallel cylindrical lenses, similar to that due to Lippmann, but in his case developed by him for integral viewing.

Two-Picture 'Integral'

To a certain extent the development of screens for integral viewing and screens of an integrating type primarily designed for two-picture fixed-stance viewing seems, for a time, to have been a parallel one with consequent borrowing and adaptation on both sides. It is at this stage that the work of Kanolt and later that of Bonnet in the development of integral-type stereo-stills becomes important. The basic method here of swinging the taking camera in an arc centred on the subject with the film maintained parallel to the chord of traverse 'pans' the compressed slit-type images across the focal planes at the back of each of the cylindrical-lens lenticulations of a plastic sheet in contact with the film emulsion. The analogy of concept here to that of the parallax panoramagram to be discussed later is noteworthy, but at the moment it would be well to turn aside to consider three examples of the two-picture fixed-eyes technique which can be thought of as deriving from these *integral* developments if only in the similarity in the concept behind the types of screen employed.

The first of these, due to Noaillon in France, sought to overcome striation apparent in the viewed pictures of the elementary grid form by oscillating the constituent grid wires; a device which unfortunately failed to make invisible the grid pattern during the periods of phase reversal in the oscillations, but otherwise achieved much in overcoming to some extent the loss

of half of each constituent left- and right-eye picture and in improving the illumination. Noaillon also conceived a basic form of auditorium with a floor sloping towards the screen whereby the limitation of stereoscopic viewing to virtually one particular distance only from the screen was in some measure ameliorated.

The next advance is noteworthy. Following the lead of Noaillon, Savoye enclosed his screen by a rotating truncated cone, apex downwards, which carried the bars of his grid across the field of view in front of the screen. The bars decrease in width towards the bottom, and would pass, if produced in imagination, through the same point through which lines in the plane of the screen and on the sloping auditorium floor would also preferentially pass. The grid cone rotates at some fifteen to twenty revolutions a minute to give an effective occultation frequency of forty-eight per second. By such means Savoye has succeeded in eliminating the discontinuity in the projected images and made the 'striation' of his grid invisible. The effective illumination is claimed as being as high as 45 per cent. whilst the effects of diffraction are stated to be largely if not entirely absent. The inclination of the grid towards the spectator, as in the Noaillon analogue, enables the stereoscopic effect to be visible over distances claimed to extend from twice to ten times the screen width.

It is to be noted that the viewing system of Savoye can be considered as another alternative to the four *viewing aids* discussed later on. The fact that the form of viewing employed depends upon a device substantially at the screen and not at the eyes, thus obviating the use of 'spectacles' in any form, makes this practical system, subject though it may be to limitations due to size and bulk, a very notable by-product of the *integral* concept in solving the two-picture fixed-stance without spectacles problem, and as such can be regarded in the writer's opinion as the only practicable system to date which can dispense with some form or other of a viewing aid at the eyes.

The Russian Stereo System

A third two-picture system of a somewhat similar type has been elaborated by Ivanov of the U.S.S.R. and has been shown

in the Moskva theatre in Moscow in recent years. Originally the two pictures were taken side-by-side on one film with a vertical beam-splitting mirror attachment* at the camera, a similar attachment being used in projection on to the screen in front of which was suspended a large iron frame supporting a grid of strained piano wires, the weight of the whole being of the order of tons. The system has been modified of late by changing the 'viewing aid' from a grid to a large number of spherical lens surfaces worked on a transparent surface placed in front of a mat screen. This assembly of spherically surfaced lens elements is tilted towards the audience who are accommodated on seats specially arranged in suitable rows and columns upon a flooring which rises steeply away from the screen, a device similar to that earlier used by Noaillon in France. In this way the distance of individual seats from the screen does not change drastically and the radial pattern of the columns of seats seeks to ensure that no one gets a pseudoscopic view. The diameter of the lens elements on the transparent surface in front of the screen is tapered towards the base so that in spite of the tilt of this surface and that of the auditorium, the angular diameter subtended to the viewers will tend to be the same over the whole of the surface. Considerable claims are made for the success of the system but the lack of parallel developments along similar lines in other countries would appear to discount these in the absence of more direct evidence.

Parallax Stereogram

It is the difficulty of preventing the possibility of pseudoscopic viewing, as exemplified by the elaborate seat-arrangement palliative adopted in this Moscow two-picture system, that led to the demand for an integral multi-stance alternative. The pseudoscopic limitation was removed in Lippmann's proposal of the parallax stereogram in 1908 in which the idea of using only two pictures was abandoned and substituted by the employment of a theoretically infinite number of pictures appropriate to an infinite number of stances. This was achieved by reducing the width of the grating gaps to mere slits, analogous to the pin-point aperture of the pin-hole camera. By so doing, a line-element panorama would be formed in the 'shadow' of the

bars, and was made wide in comparison with a reduced bar-width. An eye viewing such a presentation would pick up, from any given position, the line-element behind each of the bars appropriate to its stance—a stance corresponding to that of the camera when the picture was taken—and would integrate these

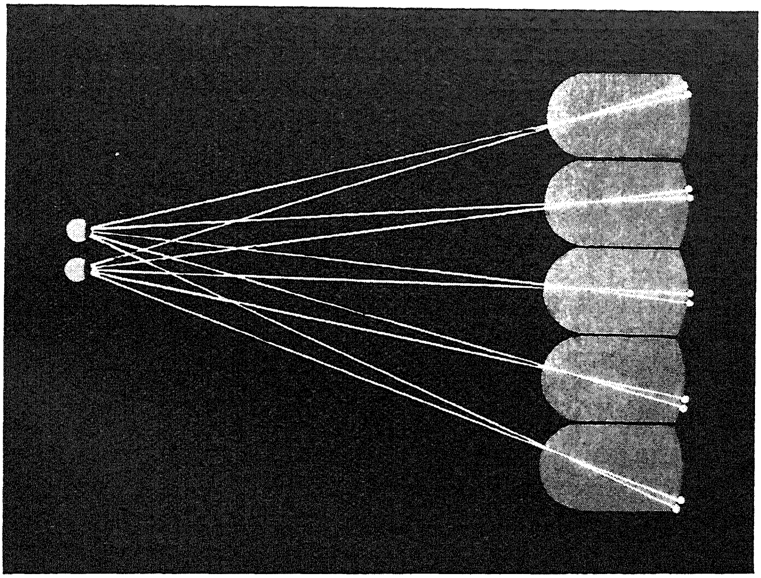

FIG. 24. *Lippmann (Integral) 'Parallax Stereogram'.* A screen is composed of a large number of parallel vertical cylindrical lenses side by side. By projection, a panorama of the photographed scene, which is appropriate to a unique stance, is formed on the mat back-surface of each lens cell. A pair of eyes, wherever placed, will pick out the pair of left- and right-eye images appropriate to the particular stance determined by the eye's position. (*Crown Copyright.*)

into a coherent synthesis of the original picture. From any other stance, an entirely different set of line-elements would be picked up appropriate to the entirely different vertical slices of rays which emanated from the taken scene that entered the camera lens when located at the corresponding taking stance. A pair of eyes could therefore take up *any* position in front of such a screen and each eye of the pair pick up a picture correctly *disparate* from the other. A further shift of the head to the left

(say) of $2\frac{1}{2}$ in. would, whilst permitting the right eye to see what the left eye previously saw, establish a correct new left-eye viewpoint instead of a pseudoscopic right-eye viewpoint as would the two-picture version previously described. Owing to the small effective aperture of the system, Lippmann further proposed the substitution of the 'pin-hole' slotted grid by vertical lenticular convex elements, of the type of a cylindrical lens, in which the front surface of these glass or plastic rods, convex in cross-section, gathered all the incident parallel light rays to focus them in a sharp line-element of light on the slightly bowed back surface of the rods.

This example of an *integral* system has not been found adaptable as yet to successful exploitation in the theatre, but it is interesting to note that a screen of this type is basic to the commercial still portraits displayed in recent years for advertising purposes. The necessary varying stance for these is achieved by the device mentioned earlier due to Kanolt and subsequently elaborated by Bonnet in which the camera is made to swing over a wide arc.

Parallax Panoramagram

The earlier work of F. E. Ives and of Lippmann was later elaborated by Dr. H. E. Ives to give in actual demonstration, what was probably the most elegant approach to date of integral stereoscopic motion-pictures. This was his *parallax panoramagram* in which the limitations of the Lippmann conception were successfully removed in laboratory practice. Lippmann intended his lenticular screen cylindrical lens-elements to act each as its own camera lens. These lens elements, being necessarily very small in cross-section and of crude curvatures largely uncorrected for distortions, formed images of poor definition, which fell off rapidly in quality with distance from the object. This can be obviated, as Kanolt had previously shown, by first forming an image of the scene by an 'auxiliary' camera lens at the surface of the screen, leaving to the latter only the function of integrating this image into lines of light behind each lens-element. The swing of the camera through an arc developed behind each lens-element a series of these lines which together formed a panorama. A camera swung horizontally is, however

inapplicable in motion-pictures practise. The parallax panoramagram of Ives, although demonstrable only in a laboratory at considerable cost, was on the other hand capable of showing stereoscopic pictures in motion for a few seconds to an audience, without viewing aids, whose members were free to move about and in so doing were presented with every changing aspect of the scene. This remarkable demonstration was made possible by ingenious and novel devices both in taking and in projection. The scene to be taken was accepted over a wide arc by a horizontal slice of a concave mirror 4 ft. long, which reflected its image, via a half-silvered mirror centrally in front of it, off to one side at right angles, to a focus on an interposed glass screen figured with vertical concave ridges. Each ridge formed potentially a panoramic series of virtual line images, and these were received by a photographic copying camera and reduced to a lantern-slide size negative, from which a positive was subsequently made. If one of these lantern slides is projected on to the matted back of a Lippmann screen and the whole system is lined up with extreme precision so that the 'image' of each concave ridge, as it were, is located exactly on each constituent cylindrical glass rod of the screen, there being an equal number of rods in the screen to ridges in the concave 'grille', a viewing pair of eyes wherever located in front of the screen will be able to pick up in each rod its appropriate pair of line images according to the stance taken and adopted, and the reproduction of the original view will be seen in stereoscopic relief. To encompass the recording of motion, thirty-two lantern slides of the original scene were made of its successive aspects over a period of two seconds. These were mounted radially round the perimeter of a large metal disc and each illuminated in turn as the disc rotated by an 'electronic' flash when centrally behind the lens objective so that accurate alignment on the lenticular screen was ensured.

THE 'FIXED EYE'

Having described the outstanding system of projection of the integrating or 'roving-eyes' type in which the viewing aids concerned can be regarded as being inherent in the system, it is expedient to return to the consideration of the more usual and

more practical systems based on a *fixed stance* for the pair of eyes in both taking and projection and in which some subsidiary form of viewing aid at the eyes is essential to differentiate between the left and right-eye views. For in the fixed eye-stance case it is clear that a bunch of rays emanating from the

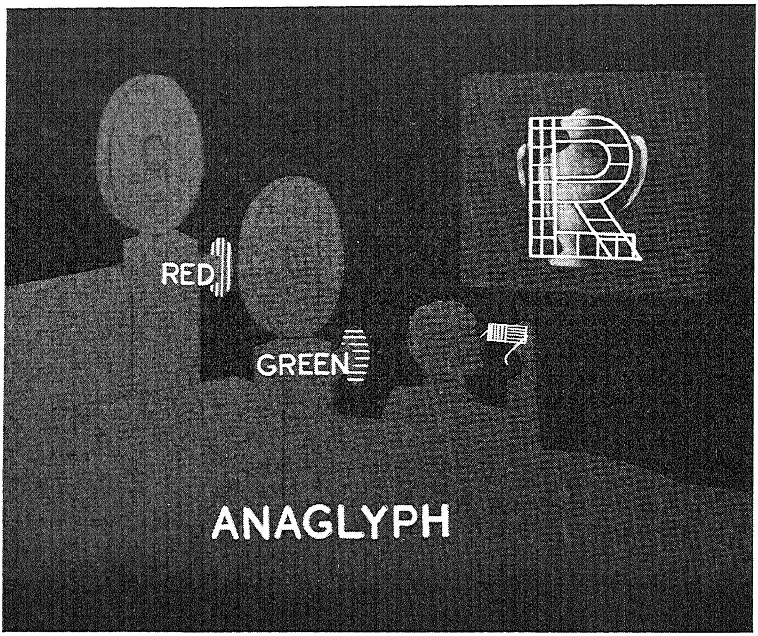

FIG. 25. *Viewing Aids: ' Anaglyph '.* The left- and right-eye films are projected through red and green filters respectively. The viewer wearing appropriate red and green spectacles, sees the picture in three-dimensional relief, as the left eye sees only the left-eye picture and the right eye only the right-eye picture.

original scene could be particular to the left eye whilst an entirely different bunch would be particular to the right eye. In any stereoscopic reconstruction of the scene neither eye, when viewing the reproduced bunch of rays appropriate to itself, must ever in any circumstances see the bunch belonging to the other. We are confined in fact to two disparate images only, each immutably associated with one or other of the eyes and not, as in the integral types of viewing, to an ' infinite ' number of view-

points and associated disparate images, interchangeable according to stance as between the two eyes.

Of the methods of restricting to each of the two eyes in viewing the appropriate disparate image, four of these *viewing aids*, as we are conveniently calling them, are practicable and noteworthy. These can be classified as being of the 'Anaglyph', Optical, Shutter-Occluding and 'Polaroid' basic types. Of these, only the anaglyph and the Polaroid types have attained to any considerable applications and of these two, the anaglyph is historically by far the older and is in any case an appropriate one to consider first.

Anaglyph

The Anaglyph principle is well known. It is based on the application of two complementary colours, usually red and green, which are mutually exclusive. A drawing, for example, carried out in red on a white background will appear to be white and indistinguishable from the background if seen through a red glass of the same hue. Seen through the complementary green glass, the drawing will appear to be black on a white ground. Similarly a drawing in green is invisible through a green glass but becomes visible through the red one. In stereo projection, when using this principle as the viewing aid, the left eye image is projected on to the screen through a red filter and the right-eye image through a green one, viewers in the audience wearing a similarly coloured spectacle glass in front of the corresponding eyes. The left-eye image on the screen being built up of varying tones of red light is visible to the left-eye in corresponding tones of white light but is invisible to the right eye. Similarly the right-eye image becomes visible as a white image to the right eye, but not to the left one. Each eye thus sees only its appropriate disparate image and the picture becomes stereoscopic. Such films were widely shown in ciné theatres for a time in the mid-1920's under the name of 'Plastigrams' and were followed some ten years later by the first stereo moving picture with sound effects known as 'Audioscopiks'. Although extremely simple to embody in a projection system as a viewing aid, the anaglyph method is inapplicable to projection in colour. It can also be very fatiguing to watch, probably because of what must be

the unnatural psycho-physiological reaction of restricting each eye exclusively to one colour only.

Optical

The Optical type of viewing aid differs from the other three in requiring the separate presentation side-by-side on the screen

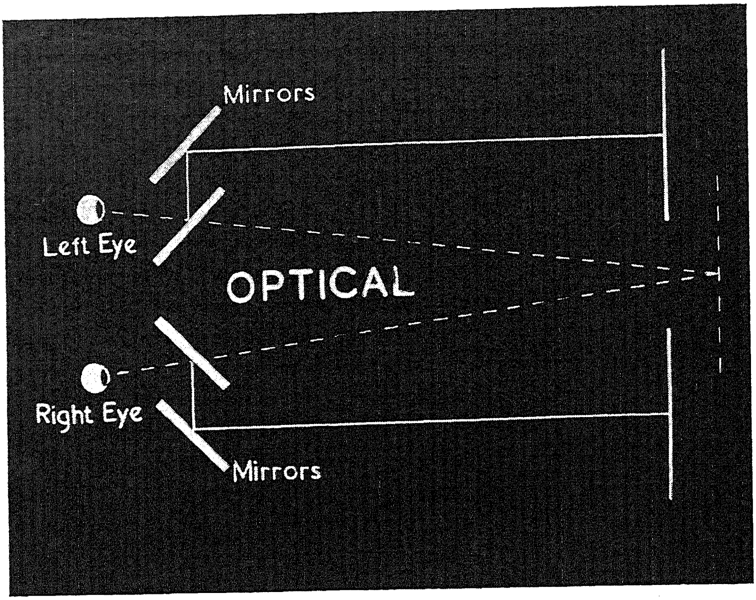

FIG. 26. *Viewing Aids: 'Optical'*. The left- and right-eye pictures are projected side-by-side on the screen and not superimposed. Each viewer, by wearing optical aid spectacles of the type shown, can see the pictures in stereoscopic relief, as each eye sees only its appropriate picture and both the side-by-side pictures are merged optically into apparent superimposition. (*Crown Copyright.*)

of the left- and right-eye images to be viewed, whereas all the others superimpose these. The optical aid has to perform two functions. In the first place, since the necessarily large images cast on the screen must be considerably more than interocular distance apart, the optical device must convert what would be a divergence to eyes viewing these direct either into parallel viewing or preferably into convergence at screen distance. Secondly it should as far as possible, permit each eye to see only its appropriate left- or right-eye picture. There are many

different optical devices which will carry out these functions. In one of these, the rays from each picture, when these are displayed side-by-side, are separately received by mirrors at approximately 45° on either side of the eyes which reflect the rays inward to two further mirrors, roughly parallel to the outer pair in each case, to reflect the rays from each picture exclusively into the appropriate eye. Either the outer pair or the inner pair of mirrors can be swung inwards slightly to provide the necessary conversion of a divergence into convergence. In a similar device, right-angled prisms are substituted for these mirrors, or the pair of mirrors appropriate to each eye may be combined into a rhombic composite prism. Both these devices are free from colour fringing defects. In a third device, two very thin wedge-shaped prisms, similar to those used in the old-time Brewster stereoscope and similarly disposed, are placed one in front of each eye to the same purpose. In this case colour-fringing of the images will not be entirely absent unless the prisms are chromatically corrected. In all three types, these optical devices may be considerably simplified and much lightened in weight by omitting one half of the combination and viewing the separate picture, previously seen through the now-missing half, directly without other aid by the appropriate eye concerned. The great advantage of the optical type of viewing aid is the negligible loss of light involved, and the practically perfect retention of definition and colour in the projected pictures. Against it is the somewhat cumbersome and heavy nature of the devices involved and the difficulty which many viewers might have in achieving a satisfactory merging of the two separate pictures in their unaccustomed handling of the fitted convergence movement. It is interesting to note that the first successful demonstration of a moving-picture in stereoscopic relief was achieved, using a viewing 'stereoscope' of the optical type, by Friese-Greene; who also incidentally produced the first 'negative' moving picture in the modern manner and the first two-colour positive motion pictures in colour.

Shutter-Occluding

In the Shutter-Occluding type of viewing aid, the left- and right-eye pictures are thrown alternately on the screen by means

of a shutter which interrupts first one then the other of the bunches of rays that go to form the two component pictures emanating from the projector or projectors. Each member of the viewing audience is provided with a pair of 'spectacles', the separate eye apertures of which are alternately occluded by

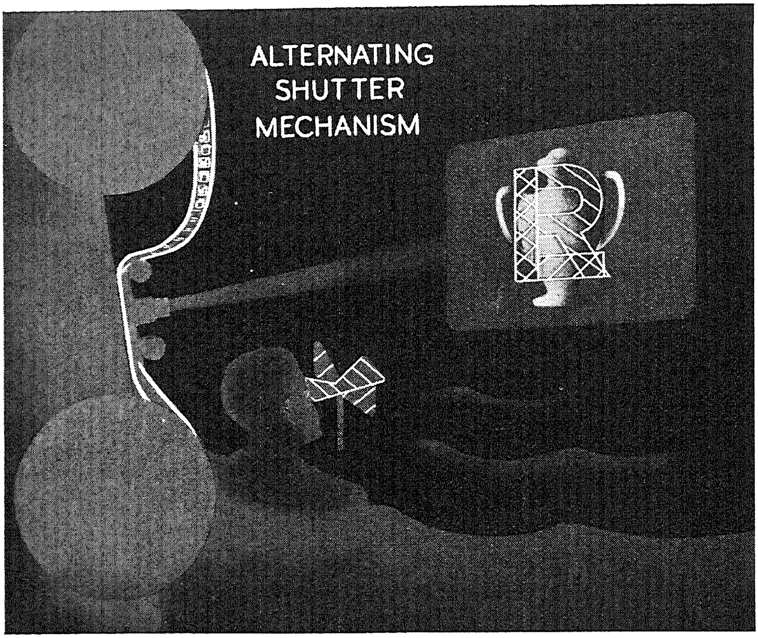

FIG. 27. *Viewing Aids: 'Alternating Shutter'*. The left- and right-eye pictures recorded say on alternate frames of the film are seen alternately, only by the appropriate eye, with the aid of an oscillating shutter mechanism in front of the eyes or incorporated in spectacles, each eye being occluded in turn.

an incorporated oscillating or rotating shutter driven by electrical or mechanical means in synchronism with that at the projector. Here again, the advantages are great, as the eyes view directly and without impediment left- and right-eye pictures virtually superimposed, and again without any deterioration in definition or colour. Its disadvantages are, however, also great. The fact that the two constituent left- and right-eye pictures are seen alternately means that either two films must be

involved in their projection at normal running speed or one film at double speed, as each eye has to be 'fed' individually at some sixteen frames per second, just as the pair have to be normally, if persistence of vision is to operate in conveying the illusion of motion. Also again, in a rather similar fashion to the anaglyph, the individual and separate treatment accorded to the eyes arouses unnatural psycho-physiological reaction which, at least if prolonged, can be fatiguing and productive of eye-strain. Additionally there are also the installational and operational difficulties in driving the shutter-spectacles, and the doubtless unfavourable reaction on the part of the participating audience to a 'gadget' anchored to the seats by some form of driving connection.

Polarizing

The supreme viewing aid discovered so far utilizes polarized light to discriminate between the left- and right-eye pictures, especially in its 'Polaroid' embodiment. The basic principle underlying all variants of the application of polarized light is that the left- and right-eye pictures are projected by means of light mutually polarized at right angles, being then thrown on to a non-depolarizing screen and discriminated by corresponding polarizing filters at the two viewing eyes. Prior to the invention of Polaroid by E. H. Land in 1927, methods of applying polarizing principles were costly and bulky, involving as they did the use of rare double-refracting crystals such as Tourmaline, or of Iceland Spar cut at a special angle and recemented to form a 'Nicol' prism; or alternatively, of bundles of plates of glass set at a particular angle. Filters of the Polaroid type are, on the other hand, relatively cheap and light, being made in thin plastic sheets which have been stretched to align the constituent polarizing molecules parallel to the stretch. Light passed through such filters emerges polarized in a plane parallel to the stretch, with a transmission factor of roughly 40 per cent. Its neutral tint ensures that colours are transmitted with little appreciable degradation. It is easily produced in the form of spectacles in which, for the purposes of stereo-viewing, the planes of polarization are set at 45° to the vertical and at 90° to each other. Set this way, instead of one plane vertical and the other horizontal,

permits of their use either way round, i.e. back-to-front, a considerable advantage if they are of the ' cardboard ' mounted type, held up to the eyes.

It is not too much to say that the use of Polaroid as a viewing aid has made stereoscopic projection, and in colour, not only

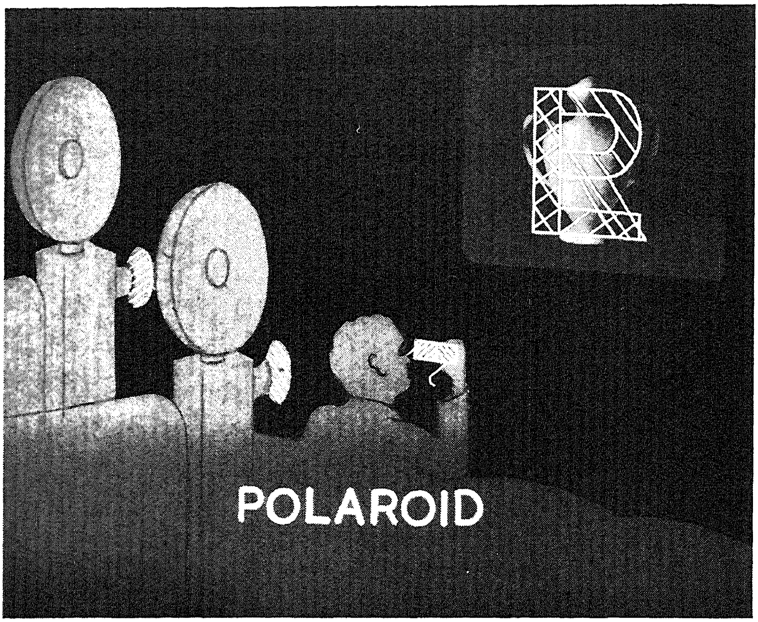

FIG. 28. *Viewing Aids: 'Polaroid'.* Each of the left- and right-eye pictures on the film or films is polarized by filters in directions at right angles to each other. The viewer, wearing appropriately oriented polarized filter glasses, sees only the left image with the left eye and the right image with the right eye, the two planes of polarization being mutually exclusive.

practicable but near-perfect. No system of stereo projection to date which sets out to dispense with a viewing aid of this type is at all comparable in its results or, in view of the limitations of possible technical advances in sight, within measurable distance of being so. Its disadvantages are few. The main disadvantage, which it shares with the three other types of viewing aid, is that of the necessity of wearing ' spectacles ' anyway. Another major disadvantage is the considerable light loss involved.

Minor disadvantages, in which nevertheless improvements are doubtless constantly being made, lie in the slight deterioration in the definition and in the colour rendering of the transmitted image, due not only to the effect of the enclosing glass of the filter and to its figuring, but also to that of the filter material itself. A further disadvantage lies also in the bleaching which the filter material may suffer in the powerful illumination experienced by it in the projector light beam. When all is said and done, however, the simplicity and effectiveness with which filters of the Polaroid type meet the requirements of a viewing aid are so marked that its deficiencies are relatively insignificant in comparison.

CHAPTER V

PROJECTION METHODS AND SYSTEMS

We now come logically to a consideration of to-day's practical *systems* which are all of the fixed-stance two-picture type. All can conform either fully or in part to the four requirements of stereo projection, in adopting one or more of the three basic methods of projection which are alternative to ' parallel ' projection. All, with the exception of the system due to Savoye, employ Polaroid as the preferred and almost indispensable viewing aid.

There are *four* basic forms that these projection systems can take. In the first of these *two projectors* are used, implying the use of two cameras and two films. The advantage of such systems lies in their employment of the full-size normal ciné frame and its associated ' normal ' full-frame definition; with the offsetting disadvantages of expensive duplicated equipment, requiring synchronization and the additional expense and trouble of duplicated films. The second type seeks to retain the definition advantage of full-frame projection, whilst getting rid of the disadvantages which follow upon the use of two of everything, by recording the left- and right-eye images on *alternate frames* of a single film. The disadvantages here are the duplication of the speed of the film and its associated double cost, together with accelerated wear-and-tear of film and mechanisms. The third type abandons full-frame definition to avoid these major and abnormal disadvantages of the first two types by recording both the left- and right-eye images on a single frame of a single film usually through the agency of some form of

beam-splitter. A loss in definition of the order of one-third is the major disadvantage; the price to be paid for the extreme simplicity and economy in the equipment that is concerned. The fourth method, which normally has some attributes in common with those of beam-splitting, also records the two constituent images of the stereoscopic pair on the single frame of a single film through the agency of a *twin-lens*, substituted for the normal single lens of the 'straight' camera and used in conjunction with an attachment similar in form but not quite in principle to a beam-splitter for accepting the scene photographed from two stances at interocular spacing and transferring these to the side-by-side 'inputs' of the twin lens. The major disadvantage is again a similar loss in definition and additionally there is a loss in flexibility; but there is no keystone distortion as can occur in a true beam-splitting device.

FULL-FRAME SYSTEMS

Norling Two-Projector System

Taking practical examples of these now in order, an outstanding exponent of the two-projector system is that due to J. A. Norling who, incidentally, was responsible for the anaglyphic 'Audioscopiks' of 1935 previously mentioned, and for his notable exhibition of Stereo-projection for the Chrysler Corporation at the New York World's Fair of 1939. The Norling camera, which is fully engineered, combines in one camera body the essential features of two film camera mechanisms and magazines running closely side-by-side in synchronization. The two novel and impressively ingenious features that adapt the combination to effective stereo versatility in photography are the variable lens-spacing and the provision for a variable convergence. The variable lens-spacing is achieved by setting up in front of the two closely adjacent camera lens two rhombic prisms, each with its light 'delivery' end centred in front of one of the lenses, and the light accepting 'pick-up' end free to be swung outwardly and downwardly about the lens in opposite directions. Rhombic prisms do not re-orientate their transmitted images when changing their own orientations. The effective inter-axial distance of the two

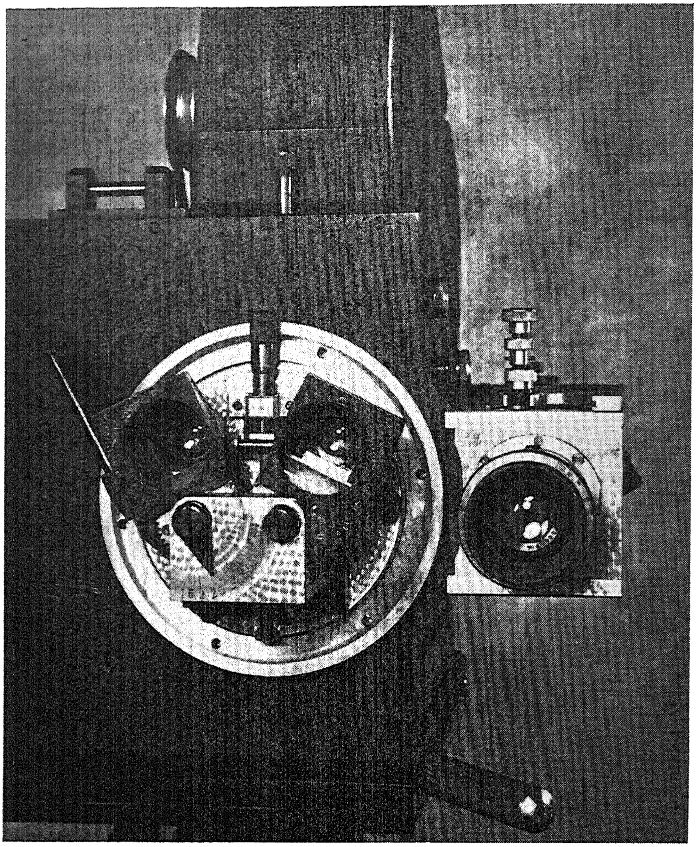

FIG. 29. *Norling System.* Close up view of camera showing swinging-prisms variable interaxial movement, variable convergence movement micrometer operated and (monocular) view-finder on right. (*Courtesy: John A. Norling.*)

lenses can be varied from $1\frac{1}{2}$ in., the actual distance apart of the two lenses, to $4\frac{1}{2}$ in., the width apart of the outer ends of the rhombic prisms when swung fully outwards to lie horizontally in opposite directions. Variable convergence is effected by an inward shift, micrometer-screw operated, of the camera lenses towards each other with respect to the fixed films. As will be seen later, this movement is of a type which is free from keystone distortion effects.

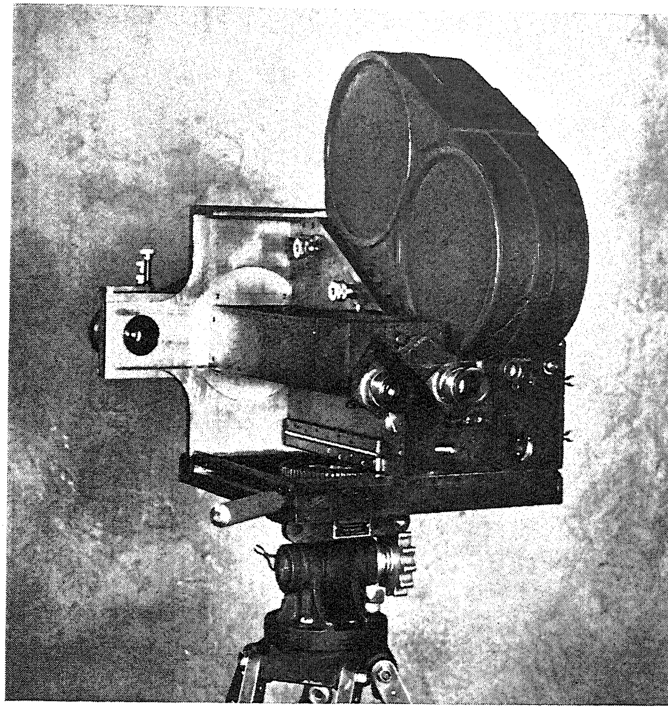

FIG. 30. *Norling System.* Rear view of the camera showing the double magazine accommodating two rolls of film and also the binocular view-finder which permits the cameraman to compose his scene stereoscopically. (*Courtesy: John A. Norling.*)

Dudley Modification

A modification, due to Dudley in England, by a stereoscopic artifice originally applied by Norling to still cameras, provides a less costly alternative when the provision of two cameras and two projectors equipment is contemplated. The difficulty in placing two ciné cameras side-by-side, each probably much in excess of $2\frac{1}{2}$ in. thick, so that the separation of their lenses shall not normally exceed $2\frac{1}{2}$ in., the interocular distance, is avoided in this variant by mounting the two cameras facing each other on an ' optical-bench ' type of tripod-head. The camera lenses each carry, attached to their mountings, a surface-silvered mirror at 45° to the optical axes of the lenses, the two mirrors being

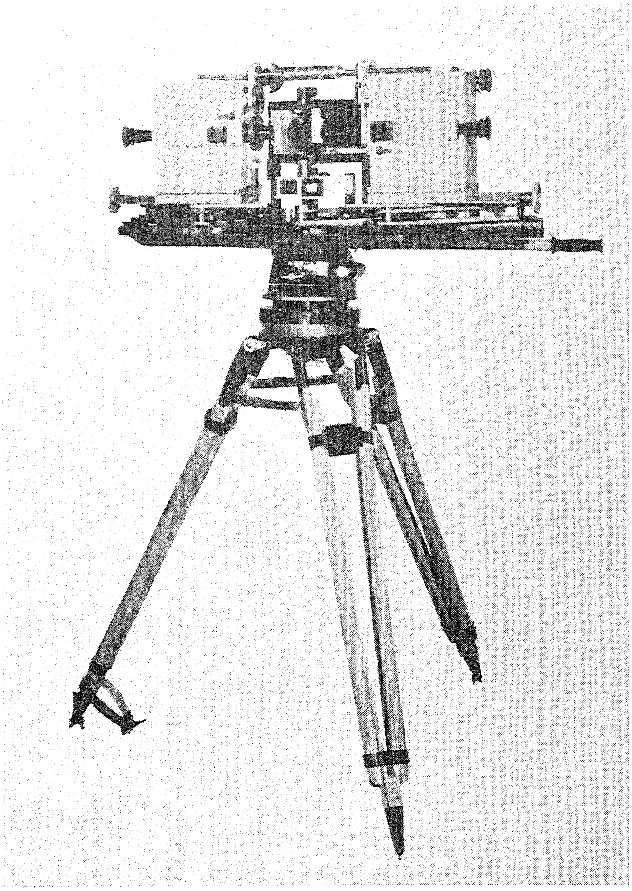

FIG. 31. *Projection System: ' Dudley Two-Camera '.* Two (Sinclair) 35 mm. Ciné cameras face each other and ' look ' into a pair of mirrors at 45° to each other and facing the subject. The spacing apart of the mirrors can be varied to give in effect a variable camera spacing other than interocular if required and the angle between them can be varied to give a converging camera system. The system is applicable to all types of camera. (*Courtesy: L. P. Dudley.*)

at 90° to each other, facing outwards towards the scene to be taken. A movement is provided whereby these 45° angles may be varied slightly simultaneously to give convergence; whilst an effective lens-separation down to $2\frac{1}{2}$ in. or less can be attained

by approaching the two camera lens-mirror assemblies towards each other. The convergence movement is not, however, free from keystone distortion effects in this particular variant.

Bernier Alternate Frame System

A practical embodiment of the *alternate frame* system is one due to Major Bernier, U.S.A.F., who sets out to rid this method

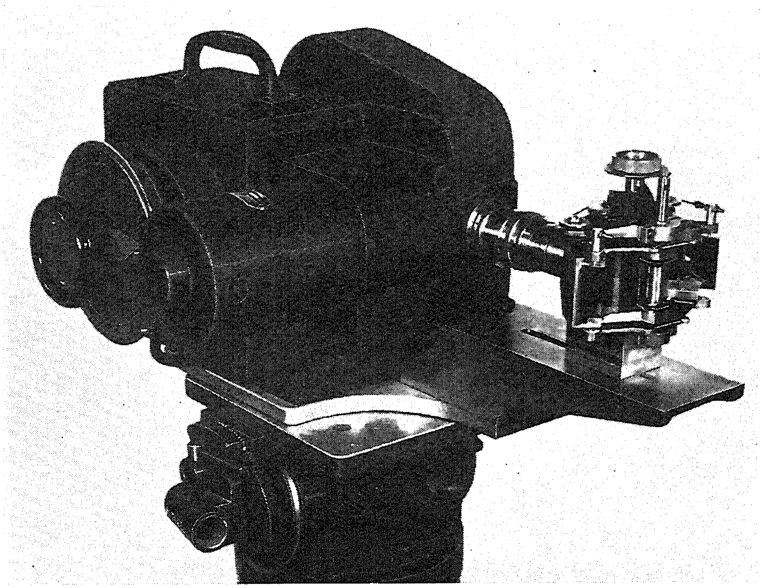

FIG. 32. *Bernier Alternate Frame System.* The polarizing beam-splitter, described in the text, shown attached to an Eastman 16 mm. High Speed Ciné Camera. (*Courtesy: Major Bernier.*)

of the great disadvantage it has of doubling the film running speed by incorporating in his projector a 'Morgana' type sprocket-drive movement which shuttles one frame backwards for every two forwards. This movement, in conjunction with that of a synchronized barrel-shaped attachment, which rotates a polarizing filter in front of the lens to pass alternately light in axes of polarization at right angles to each other, results in an acceptable projection whose flicker rate is some thirty-six frames per second. A further novelty in the system is the method by

which the alternate frames are taken on the film by the attachment to the camera lens of a synchronized rotating barrel polarizer, similar to that used on the projector. This, in conjunction with a vertically split left/right polarizing filter in the lens barrel together with a vertical beam-splitter of a side-by-side type to be

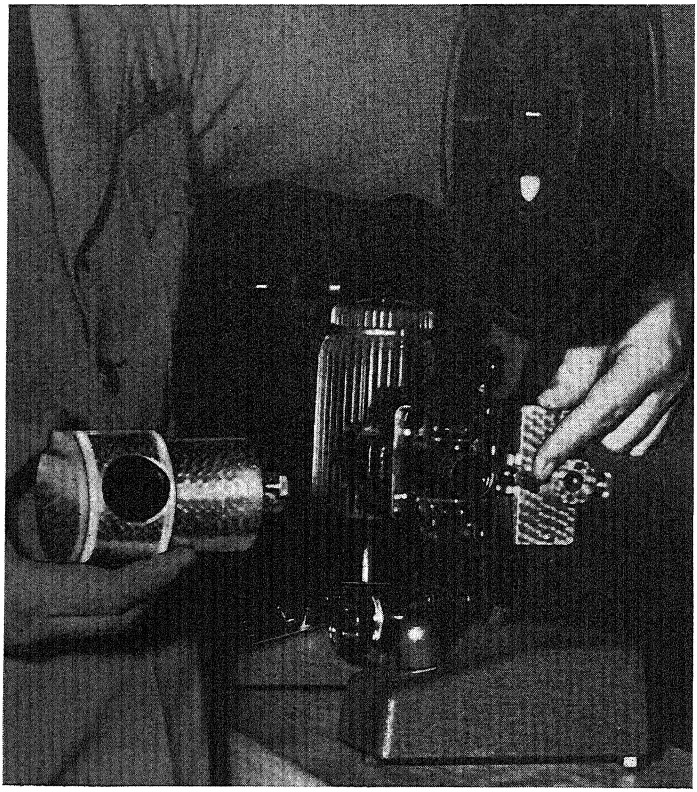

FIG. 33. *Bernier Alternate Frame System.* The synchronized rotating polarizer is shown detached, on the left, from its normal position in front of the projector lens. The drive for the polarizer, taken from that of the Morgana type Bell and Howell 16 mm. Projector, is being indicated by the forefinger. (*Courtesy: Major Bernier.*)

described later, eclipses alternately the left- and right-eye views which are picked up by the two halves of the beam-splitter working in synchronism with the alternate frames passing

through the film gate. Variable lens-separation can be effected by a movement of the outer pair of mirrors of the beam-splitter whilst convergence, not however keystone-distortion free, can be obtained by swinging these same mirrors equally about vertical axes.

Disadvantages in the system would appear to be in a limitation in the slow rate of moving subjects that can be photographed, imposed by the Morgana type of frame shuttling, and in the loss of light, amounting to two stops of effective aperture, due to the adoption of double Polaroids as left- and right-eye view selectors at the camera lens.

Dudley Beam-Splitting Anaglyph System

The major advantage in two-projector systems of projection, such as those of the Norling and Dudley types respectively, lies in the full normal ciné frame which can be employed for each of the left- and right-eye pictures. This feature ensures that the definition of the stereo presentation will not be inferior to that of a ' straight ' ciné picture of corresponding frame size. This advantage, it will have been seen, is also shared by systems of the alternate-frame type as exemplified in that due to Bernier. All these systems, however, have, as has been mentioned, their own particular associated disadvantages which offset to some extent the indubitable advantage of full-frame definition. In an ingenious effort to retain full-frame definition, whilst yet avoiding the disadvantages associated with such systems as have been already reviewed, Dudley has produced a further system—based on a beam-splitting method—in which the artifice used for discriminating, whilst yet superimposing the two constituent left- and right-eye pictures in the camera, is based upon those same anaglyph principles which, as we have seen, could be used as a viewing aid in projection.

In essence, the system depends upon the attachment in front of the taking camera of an unsymmetrical beam-splitter which consists of a half-silvered mirror in front of the camera lens, and at 45° to the lens axes horizontally, facing an offset fully silvered forward-facing mirror, again at 45°, at a distance of some $2\frac{1}{2}$ in. Two rays of light are therefore accepted from each constituent point in the scene being taken, with a lateral

displacement equal to the interocular distance apart of the eyes, on the surface of the two mirrors. The rays striking the offset mirror are reflected at right angles sideways on to the surface of the half-silvered mirror on the optical axis of the lens and from thence reflected again through 90° into the camera lens. The rays striking the half-silvered mirror direct, on the other hand, pass straight into the camera lens without any deviation except for a negligible lateral displacement due to the thickness of the glass. Alternatively the mirrors may be replaced by three right-angled prisms, the first being the offset one and the other two being combined together at their common diagonal faces, one of which is half-silvered. This cube, or the half-silvered mirror in the other version, can be made to swivel inwards slightly so that the left- and right-eye rays from an object in the scene being taken can be made coincident upon the film. Discrimination of the two full-frame left- and right-eye images at the film is effected by two filters, one in front of each mirror or prism, the colours of these being mutually exclusive red and green on the anaglyph principle. Colour film of the three-colour monopack type is used. In effect therefore the final colour representation is dependent upon two colours superimposed, after reflection at a part-silvered surface probably possessing colour discriminating characteristics, as registered by a three-colour process. The same attachment can be used in projection, the audience wearing anaglyph glasses as the viewing aid. It is presumably yet to be established that the human eye is capable of the double task of combining the left- and right-eye pictures both for the synthesis of colour and of depth, separately and simultaneously without fatigue, especially in prolonged viewing. It may also be fallacious that full-frame definition can be attained by what is, in effect, the superimposition upon an emulsion, whose capacity in recording detail information must be limited, of the detail of two full frames into the one full-frame area.

Wright Double Polarizing System

Before continuing the review of practicable systems of stereo projection with descriptions of those falling into the beam-splitting and twin-lens classes, it will not be out of place to

mention an alternative to the almost universal use of Polaroid as a viewing aid in which the severe light loss in the latter could be markedly curtailed. It is obvious, in the general method of using Polaroid-type filters as a viewing aid, that at least half of the available light is wasted at each of the left- and right-eye projector objective filters, as of course each must discard all that half of the available light which is at right angles to the half which it passes. In a system devised by Edwin Wright, advantage is taken of the properties of certain crystals whereby incoming light is doubly refracted to form the bundles of rays in two different directions whose planes of polarization are mutually at right angles to each other. Each of these beams, which originate from the same light source, is used to illuminate equally, and without of course the previous loss of half the light, the two half-frames corresponding to left- or right-eye views on the film or films.

We now come to the third basic method of stereo-projection, *beam-splitting*, which records and projects both left- and right-eye images by means of attachments on to the one ciné frame. Only one camera and projector, both unmodified, are used in conjunction with only one film, running at normal speed.

BEAM-SPLITTING AND TWIN LENS SYSTEM

There are two important ways in which the normal ciné frame, the proportions of which are four horizontally to three vertically, may be split. We may either split the frame *vertically* down the middle to give two half frames which, when superimposed, give a combined frame of the proportion two horizontally to three vertically; or we may split the frame in the same way and *rotate* it through 90° to give a superimposed half-frame proportion of three horizontally to two vertically. The first type of beam-splitting is the easier to accomplish, needing only two reflections (or a multiple) for each half beam—four reflecting surfaces in all. The second type needs an odd number of reflections for each half-beam; but one reflection only is impracticable, except in projection, and the usual total number of reflecting surfaces required is three for each half-beam. In spite, however, of this added complexity, the resulting

familiar horizontal ' format ' is more suitable for ciné projection than a vertical one and, as will be seen later, the rotating type of beam-splitting can have other marked advantages in economizing film-width in convergence and in masking.

Vertical Beam-Splitters

Taking the vertical type of beam-splitters first, let us review in turn the various devices to a large extent applicable only to still photography, which have led up to or become in their own right, practicable ciné stereo-projection systems. This type really dates back to the original invention of the Stereoscope by Wheatstone, well over a century ago. The Wheatstone Stereoscope was in effect a beam-splitter consisting as it did of a pair of contiguous mirrors at 45° to each other, which reflected two parallel images of disparate pictures, facing each other and disposed laterally on either side, into the two viewing eyes in front of the mirrors. Barnard, in 1853, took the next step in proposing two further mirrors parallel to the first and disposed laterally on either side of them which would enable the two pictures to be put side by side in the same plane, facing the viewer. At a later stage Dinesmann used this disposition of the four mirrors, in a form suitable for attachment to a still camera, to which later on still, Judge added the facility of convergence by a simple device for swinging or toeing-in the pair of outer mirrors equally. The first notable advance, however, was made by the firm of Leitz between the Wars in producing commercially the ' Stereoly '. This was a prismatic embodiment of the Barnard principle and was noteworthy for its optical and mechanical design. It was much smaller than a mirror counterpart could possibly be and was attached by a simple form of bracketing to the Leica camera, for which it was primarily designed. It was not, however, fitted with a movement to give variable convergence but incorporated in its design a compromise angle of toe-in which, to a certain extent, could be in effect varied in three fixed steps by a simple spacing adjustment incorporated in the bracketing attachment. To accompany this camera beam-splitter, a prismatic viewing stereoscope was made available through which the reversed film, or a positive copy, was fed in a continuous strip.

The next logical step in developments towards a system which could be used for ciné projection was the appearance of the ‘ Stereo-Tach ’. The Stereo-Tach was in effect a development of the Dinesmann mirror beam-splitter, carried out in surface-silvered mirrors and housed in plastic. For the first time the form and the bracketing provided were such that attachment to any miniature still camera was possible. The compact beam-splitting stereoscope provided in plastic was a neat and necessary adjunct. A notable accessory was that of an alternative objective for a still projector—the ‘ Stereo Jector ’—which enabled still pairs taken with the Stereo-Tach to be projected and viewed upon a screen in three dimensions, using Polaroid as a viewing aid. Although the firm of Leitz had also produced an attachment for projection, the simplicity of the ‘ split-lens ’ type Stereo Jector and of the camera beam-splitter made available equipment which could, with a little skill, be bracketed to a ciné projector and camera, although the impractibility of providing the essential convergence necessary at both camera and projector was, however, an adverse factor, in such an improvization.

TWIN LENS SYSTEMS

A drawback in both the Stereoly and Stereo-Tach Systems of producing stereo pairs lies in the fuzzy ill-defined vertical dividing line, or *vignette*, inevitably formed between the left- and right-eye pair of images when only the existing single lens of the camera is used with a beam-splitter. This strip of fuzziness, whose width depends on the aperture at which the lens is used and upon the spacing of the beam-splitter from it, is one which is useless stereoscopically owing to its lack of sharpness and falling-off in density; and is one that can otherwise in certain circumstances become a positive nuisance owing to the ‘ overflow ’ of each of the images into the ‘ wrong ’ half-frames, to produce ‘ ghost ’ images. A cure for this might at first sight appear to be the insertion of a vertical plate between the middle of the film and the centre of the lens, but apart from constructional and operational difficulties, to do this would involve the restriction of the lens opening from the shape and size of a full circle to those of a semicircle for each half-frame, resulting in a reduction

in the effective working aperture, at least for all the lens stops except perhaps the very smallest.

Zeiss Stereotar

To overcome this restriction, whilst conferring certain other benefits, the firm of Zeiss just prior to the beginning of the Second War designed the ' Stereotar ' attachment for their Contax miniature still camera. This was based on the substitution of the existing standard lens of ' normal ' focal length by a lens-panel containing two small lenses side-by-side, separated at the rear by a vertical partition running back into the camera and virtually splitting this into two smaller cameras. These smaller lenses had the shorter focal length of 35 mm. to restore a ' normal ' angle of view to the smaller cameras equal to that of the replaced undivided one. As, however, the spacing between the lens axes was now necessarily some 18 mm. only, the distance in fact between the centres of the two half frames appropriate to each ' half camera ', recourse was still necessary to a ' beam-spreader ', of a type similar to the vertical beam-splitter, bracketed in front of the lens-pair to give, by a double reflection on each side, an effective lens separation equal to that of the interocular distance. This beam-spreader was still of the fixed prism non-variable convergence type. The lens separation was, however, made slightly less than that between the centres of the half-frames to give a small fixed toe-in so that, with the beam-spreader in position, the two optical axes converged at a point some few feet away from the camera where the majority of usual subjects were likely to be located. By removal of the beam-spreader, incidentally, the additional facility of taking very small objects very close up with an appropriately much smaller toe-in convergence became an additional attractive feature of this equipment. A limitation of the system nevertheless was the small maximum aperture available, F4, as compared with that of the ' straight ' lens equipment, F2. Here again a foretaste of things to come lay in the provision of projection equipment for the processed still pairs. Projection was effected by a special objective which carried two thin deviating prisms in the lens barrel for merging the left- and right-eye images on to a screen of a stipulated size at a fixed distance. An additional

and novel feature was the provision of an extra pair of polarizing filters immediately in front of the transparency. These, in conjunction with those on the other side of the objective lens ensured the elimination of half-frame images being transmitted in projection by the wrong half of the lens and so aided the suppression of ' ghost ' images. This system was, however, restricted to the production of still pairs and their subsequent projection in three dimension as stills.

Early Kern Twin Lens Equipment

Experimental ciné camera equipment for stereo photography and projection on somewhat similar lines had been produced by the firm of Kern, making use of closely spaced *twin lenses* over twenty years ago and in this respect was doubtless anticipatory of some features of the Zeiss equipment. In this Kern ciné camera of the late nineteen-twenties, two rectangular apertures at interocular distance apart in the front of the camera transmitted, by prismatic assemblies, the left- and right-eye views so accepted to lie imaged longitudinally side-by-side across one half of a 35 mm. standard ciné frame on a horizontally running 35 mm. film, having passed through two ' 16 mm.' twin lenses situated closely together, one above the other, in front of the film gate. The film ran at half the normal speed; thus pairs of 16 mm. frames were recorded first across the top, and then the bottom half of what would, in normal use, be the 35 mm. frame on the film. The Bolex stereo projection equipment, now placed on the market by Kern-Paillard, can trace its descent from this ingenious and precocious progenitor.

Kern-Paillard Bolex System

In this new Bolex-Kern system, two further problems had to be solved in extending a still system of the Zeiss type to motion-picture use. The first of these, and by far the major problem, was the design and manufacture of the *twin lenses* which are to replace the existing lens in the 16 mm. camera. The requirements for these amongst others are: a working aperture up to a maximum capable of handling colour under poor lighting conditions; and an angle-of-view roughly the equivalent of the original replaced lens. As the system employs

vertically side-by-side images recorded by twin lenses in conjunction with a beam-spreader, the width of the half-frames on the film horizontally would have to be that of half the 16 mm. frame-width, i.e. the focal-length of each of the lens pair, to meet the angle-of-view requirement, becomes in effect

FIG. 34. *The Bolex System.* The accessories required for a Bolex Movie Camera and its associated projector consist of a twin lens attachment, view-finder mask and standoff bracket for the camera, together with a special twin-lens type of objective for the projector. (*Courtesy: Paillard Products Inc.*)

that of the ‘ normal ’ lens of an 8 mm. ciné camera. The design and manufacture of 8 mm. ciné lenses verges on the extreme in any case and is difficult enough; but in the present case two such lenses, and identical ones at that, have to be mounted within the restricted space of one 16 mm. lens and at only half the distance of the lens back surface from the film as compared with what it was before. Further, the iris-diaphragms of the two lenses must be coupled accurately and identically, the operat-

ing movement control being brought out to an accessible position on the combined lens mount front. The design too of the rotating shutter of the ciné camera concerned had to be taken into careful consideration when ensuring that exposure times for the two half-frames via the two separate lenses were the

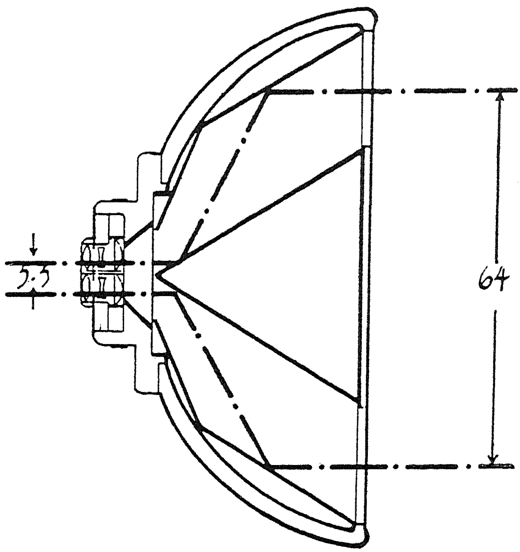

Fig. 35. *The Bolex System.* Twin Lens and 'Beam Spreader' Attachment. Schematic diagram showing the path of rays through each aperture of the beam spreader, spaced at 'inter-ocular', and thence through the prisms to the film via the two side-by-side lenses. (*Courtesy: Paillard Products Inc.*)

same. The Bolex-Kern organization is therefore to be congratulated upon solving these problems, and in having achieved a working aperture as high as *f*/2·8. It should cause no comment that the device has been made applicable only to Bolex cameras. The difficulties in design, as well as in manufacture, would otherwise have been needlessly augmented.

The basic accessory in the Bolex system is the taking lens which is screwed into the turret of the H.16 camera in place of the ordinary lens. The assembly comprises two twin lenses, with parallel optical axes 5·3 mm. apart, followed by a system of prisms of similar layout to that of a side-by-side beam-splitter

which widens the separation between the effective optical axes to the necessary 64 mm. of normal interocular spacing. The two Yvar lenses, of 12·5 mm. focus, operating at a maximum aperture of $f/2{\cdot}8$, locate the two images side by side in the proportion 85 height to 65 width, to occupy each normal 16 mm. frame on the film. There is now of course no ill-defined vignette dividing line between the two images as would occur in a beam-splitting system. The lenses are fixed-focus set at the hyperfocal distance of 10 ft., good definition thus being obtained—for a circle of diffusion of 1/50 mm. on the film—from 5 ft. to infinity at full aperture.

For projection a special duplex-lens objective assembly is provided, which replaces the standard lens in most 16 mm. projectors. It comprises two Petzval type lenses, of 20 mm. focal length and a working aperture of $f/1{\cdot}6$, whose optical axes are set parallel and spaced 5·6 mm. apart. Incorporated in

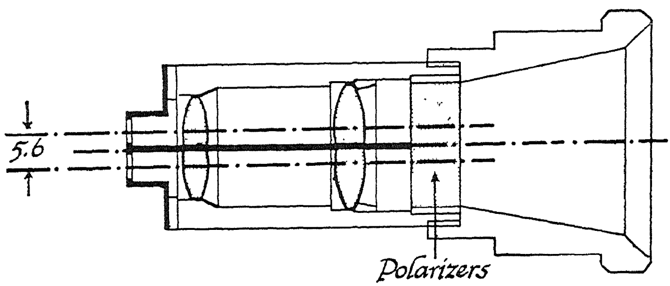

FIG. 36. *The Bolex System:* Twin Lens Projector Objective. Schematic drawing showing Petzval type twin lenses and polarizing filters. The optical axes are 5·6 mm. apart. (*Courtesy: Paillard Products Inc.*)

the assembly with each lens is a polarizer, the two being set at 90° to each other and both at 45° to the horizontal, so that polarizing spectacles such as the Polaroid 3-D Picture Viewer can be used for viewing.

To enable vision approximating that of natural relief to be presented to the maximum number of spectators, a choice of camera and projector lens focal lengths and of the spacing as between their parallel axes in each case has been made. The pattern in depth of the stereoscopic field presented to the viewer

is one in which the ' window ', through which all is apparently seen, is that which subsisted 10 ft. in front of the camera when taking. This window, recorded on the two halves of the film in the camera, will be spaced as between the centres of the two halves by approximately 5·6 mm. between centres, as a simple geometrical drawing will show. Consequently, in subsequent projection, where the projector lenses are also spaced at 5·6 mm., the window will be set up on the screen, whatever its distance from the projector, to give coincidence of its margins within 5·6 mm. The net effect of these dispositions will be that anything photographed between 10 ft. and infinity will appear behind the window; anything photographed at less than 10 ft. will appear in front of the screen. It is inadvisable to take anything nearer than half this distance, i.e. 5 ft., without having recourse to a close-up attachment which modifies the convergence of the camera lens axes and the focussing.

The focal lengths of camera and projector lenses are 12·5 and 20 mm. respectively, a ratio of approximately two-thirds. In consequence the optimum viewing distance in viewing will be two-thirds of the projector-screen distance away from the screen; or, put another way, will be at the same distance from the reproduced window on the screen as the camera was when it took the original window the same size. For spectators in the optimum viewing ' area ', the stereo reproduction is natural, whether seen in front of or through the window.

CHAPTER VI

ROTATIONAL BEAM-SPLITTING PROJECTION SYSTEMS

So far, in dealing with beam-splitting systems, we have dealt only with those that split the frame vertically. Whilst such systems have the virtue of simplicity, both in construction and operation, they are not without their limitations. Attention has already been drawn to the two major ones. These are that the resultant frame shape on the screen due to the vertical split is that of an 'upright' picture to which our familiarity with the usual ciné screen shape makes us unaccustomed; and the difficulty found in masking and preserving frame width. It will be obvious how the latter occurs when we consider that, in superimposing the two halves of a vertically split frame, the fuzzy inner edges at the central split of both will be located at the margins of the screen, one on each side. Since these strips are unresolvable stereoscopically they must be masked off, thus reducing the effective width of a picture of already somewhat narrow proportions horizontally. The 'horizontal' shows up, however, as the wider axis in our normal every-day visual space perception. Are there then any other practicable possibilities in splitting the full-frame to give left- and right-eye view half-frames not subject to these limitations, even though they may bring other undesirable features in their train?

One alternative is to split the frame in two by a horizontal line of division. To carry this out, at least on the usual vertically-running film, would lead to a resultant frame shape which would be unusually wide, the half-frames in any case being at different 'heights' in taking and requiring rectification vertically to bring them to the same level. With a horizontally

running film, even if this were practicable, rectification in the heights of the two half-frames would still be necessary although the actual shapes of these would now be satisfactory, being of the same proportions as in the vertical split system but with the longer side horizontal. There remains, however, the scheme of splitting and recording vertically whilst yet, by rotation and re-rotation of the two split half-images, photographing and pro-

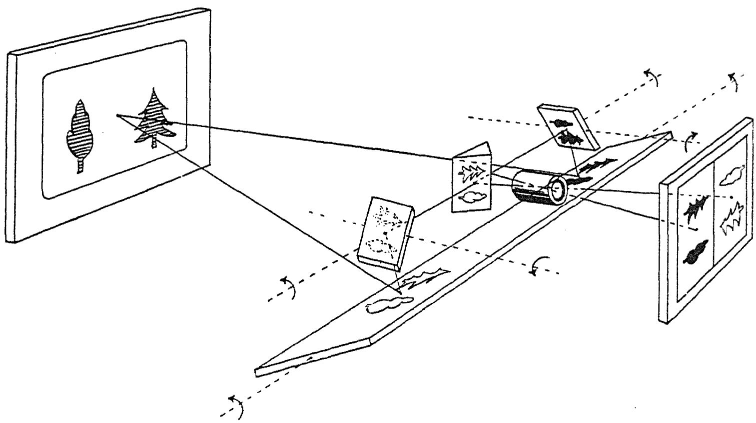

FIG. 37. *Beam-Splitting:* 'Opposite-Sense Rotation' Type. The 'scene' (or screen) on the left is faced laterally by the long 'forward-accepting' mirror at the bottom at 45 degrees whence the rays go to the 'side-throwing' pair of mirrors above to the central 'beam-splitting' pair at the centre and thence through the lens (the pictures now being rotated) to the (split) film frames on the right.

jecting these acceptable half-frame shapes horizontally. Ignoring for the moment any new disadvantages such a system might have, it should become clear that the two limitations of the vertical split system immediately disappear. In the first place, we have by rotation achieved a shape in taking and on the screen which is wider than it is high and is roughly in the proportions of that with which we are familiar. In the second place, the central split between the two half frames which is recorded vertically is, by rotation, transferred either to the top or bottom margin of the merged picture, depending upon which way we rotate, and not to the all important side margins. Valuable width is thus not lost, whatever logical and necessary

convergence 'toe-ins' that may be used either in taking or projection.

There are two basic systems of this rotational type. In the first, the rotation of each half-frame is carried out in an *opposite-sense*, i.e. one clockwise and the other anticlockwise. In the second, both half-frames are rotated in a *similar sense*, i.e. both clockwise or both anticlockwise. We shall see in due course what the respective advantage and limitations of the two systems are compared with each other and with the more usual vertical (unrotated) side-by-side splitting system.

Opposite-Sense Rotation

The earliest system proposed to embody rotation of the images appears to have been due to Mainardi. In its employment of three rotations to each half-frame, it is representative of others

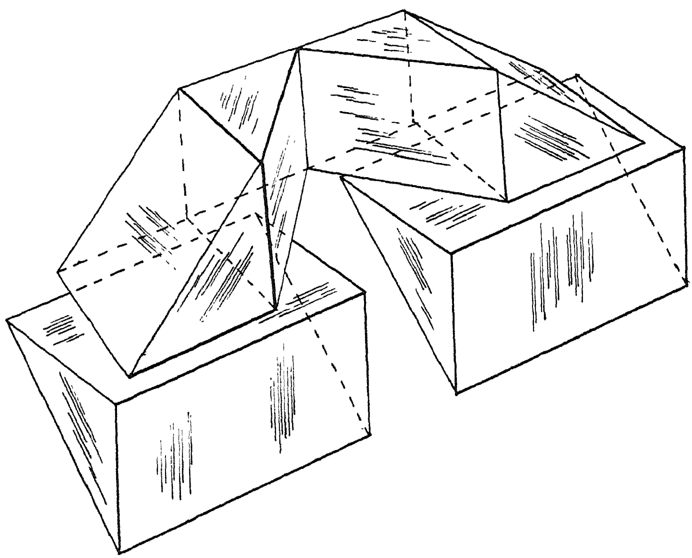

FIG. 38. *Opposite-Sense Rotation Beam-Splitting System.* Schematic Layout of Prisms.

which resemble it in this aspect. The essential features of this system lie in the provision of a beam-splitting pair of reflecting surfaces in front of the projector objective (or camera lens)

which throw the two half-frame images sideways and outwards, laterally in opposite directions, to impinge upon two further reflecting surfaces whose planes are at 45° to the horizontal and parallel to the optical axes of the objective lens. From these the rays forming the images are upcast vertically to meet two more parallel surfaces at 45° to the horizontal, but which this time are at right angles to the optical axes of the lens, from whence they are reflected forward on to the screen. A distinctive feature particular to this system is that the beam-splitting reflecting surfaces are the interior back faces of a prism of equal base-angles which are at 60° to each other. No provision is specifically made for a variable convergence movement. In the Sherbinin system on the other hand, reflection is from the 45° faces of two adjacent right-angled prisms oppositely disposed; whilst a method of variable convergence, about to be described, is the essential feature claimed for the system in its relevant patent specification. In comparing the two different methods of beam-splitting it should be noted that, in the Mainardi system, the left- and right-eye image rays cross over in the beam-splitting prism; a device which leads to a larger effective working aperture of the associated lens but at the expense of a smaller accepted angle-of-view, as compared with the Sherbinin system. As, however, the latter needs no colour correcting wedge for its 45° prism, whereas the other does for its 60° prism, the balance of advantage lies perhaps in the Sherbinin type of beam-splitting. Its method of incorporating additionally a variable convergence movement, effected by the simple device of swinging the complete beam-splitting attachment as a whole about a horizontal axis, is, however, open to criticism in that a subsequent readjustment of the direction of throw in the vertical plane is necessary to counteract and neutralize the vertical component inevitably present in the motion of the image with this type of movement.

In the Opposite-Sense rotation system due to the writer, whilst the disposition of the reflecting surface is broadly the same as in those just examined and the beam-splitting 45° prisms are used in the Sherbinin manner, an entirely novel optical-mechanical device is incorporated which gives a purely rectilinear horizontal convergence movement needing no subsequent compensatory

adjustments of the projector, and is one which is particularly adapted to the optical requirements of prismatic layouts. This variable convergence movement is attained by the deflection upwards, through an angle equal to that of the required toe-in of each of the left- and right-eye image, of both the middle beam-

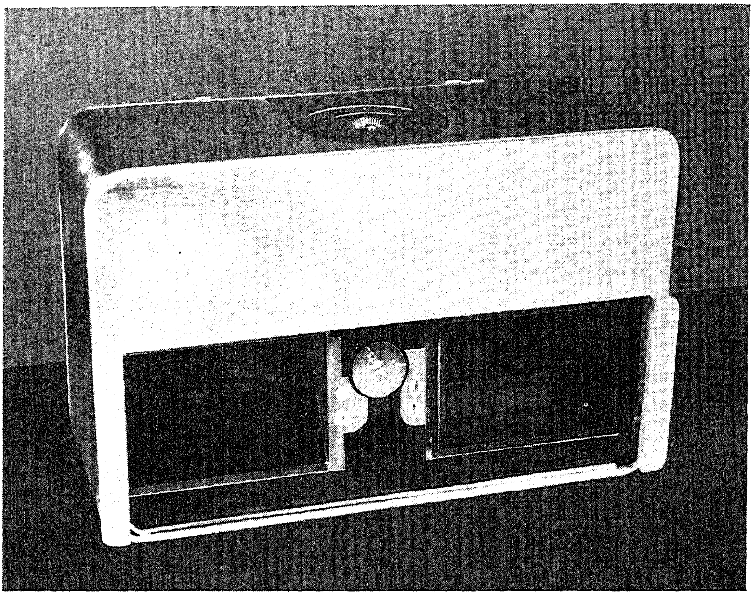

FIG. 39. *Opposite-Sense Rotation Beam-Splitting System.* The 'Universal' Attachment which brackets to sub-standard 16 mm. or standard 35 mm. ciné cameras in conjunction with any of the normal range of focal-length lenses of either. It is subsequently bracketable to any sub-standard projector for screening the single film so photographed. A scaled-up version (Fig. 46) is used for the projection of 35 mm. film. The convergence control, scaled in feet, is seen on the top; whilst the control for use with different focal-length lenses is seen in front. (*Crown Copyright photo.*)

splitting pair of prisms coupled with the upthrowing outer pair, together with a similar movement in the same upward direction of the forward-throwing prisms through half this angle. This type of movement has an important design advantage in that the beam-splitting and upcast prism pairs can be integral, thus obviating the necessity which there would otherwise be of

introducing, between the central and outer prisms, an air gap which could lead to undesirable multiple reflections between nearly parallel glass surfaces. In the design of an optional alternative projector attachment in this system, using only mirror components for cheapness, the question of possible

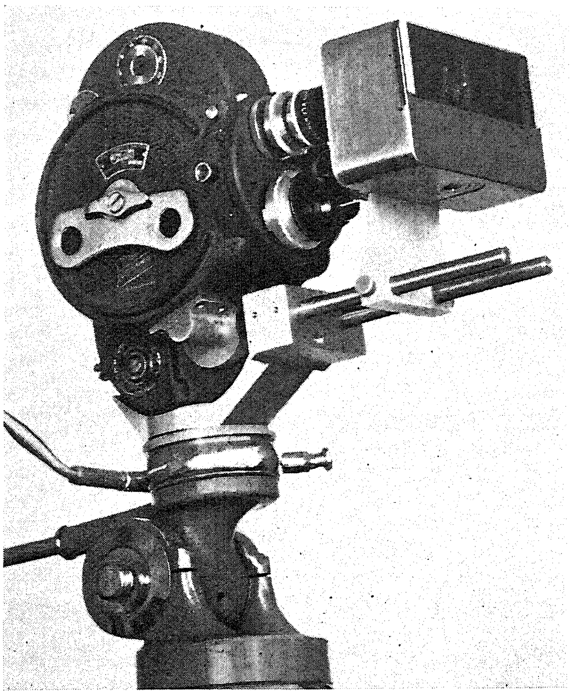

FIG. 40. *Opposite-Sense Rotation Beam-Splitting System.* The Attachment bracketed to a Bell and Howell 16 mm. 'Filmo' ciné camera. (*Crown Copyright photo.*)

multiple reflections at the (inevitable) gaps does not arise; and here a variable convergence movement can be attained by an alternative method of swinging the outer pair of upcast mirrors about their horizontal axes.

The basic Opposite-Sense rotation system, whatever its particular variant may be, suffers from a theoretical limitation which in practise, however, is fortunately of little account.

The limitation is that, since the constituent half-frame images have been rotated in opposite directions, any relative movement between the beam-splitting optical system and the film itself will result in a differential movement as between the two taken

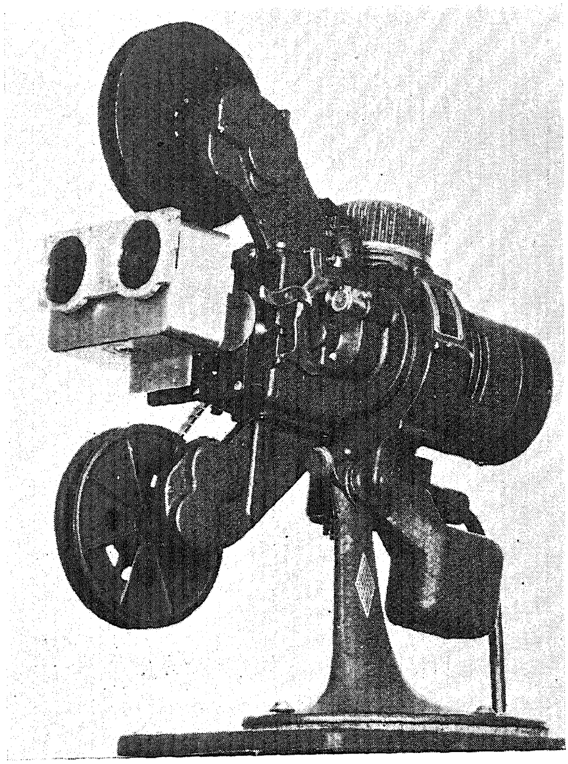

FIG. 41. *Opposite-Sense Rotation Beam-Splitting System.* The Attachment, fitted with Polariod Filters, bracketed to a Bell and Howell 16 mm. ciné projector. (*Crown Copyright photo.*)

or projected half-frames; just as in the Sherbinin converging movement where a deliberate swing of the attachment in pitch or yaw either converges/diverges or raises/lowers one-half image with respect to the other. In practise such movement is negligible with reasonably rigid bracketing of attachment to camera or projector. Alternatively the same effect could arise

if the film in the gate jitters, either up and down or sideways. Except with film that has been projected so many times that severe sprocket-hole wear has developed, this ' differential ' jitter on the screen is nevertheless minute and innocuous. The possibility of its occurrence, remote though it may be, does, however, tend to make the basic Similar-Sense rotation system theoretically attractive as differential jitter obviously cannot arise in a system in which both half-frames have been treated identically alike by being rotated precisely by the same amount and in the same direction. It is, on these grounds, the more attractive system basically, but against it there has to be reckoned the more complicated equipment involved. As will be seen later, the incidence of keystone distortion effects could make the Similar-Sense rotation system the less preferable on balance.

Similar-Sense Rotation

A system of this type was developed by the firm of Zeiss before the second war and was used by the Germans in producing three-dimensional training films-with-sound during the hostilities, particularly in connection with artillery range-finding equipment. The projection of these films in stereo, both at sea and in the field, was made comparatively straightforward and simple by the issue to combatant units concerned of highly developed kits of equipment. The key unit in these was the ' Stericon ' projector attachment. This consisted of the attachment proper, mounted in a large diameter cylindrical housing which was carried on the end of a smaller tube containing a standard 35 mm. ciné projection lens. The whole unit is substituted for the existing objective in an otherwise standard projector. The working and moving parts of the attachment consist of two ' Dove ' type inverting prisms which are mounted opposite each other on either side of the optical axis of the objective; the internal reflecting surface of the one being substantially parallel to the other and to the optical axis; both being oriented at 45° in the same sense to the horizontal. Each of these inverting prisms could be preset slightly by an adjustable screw about axes ' within the surface ', parallel to this same 45° line, through small equal and opposite angles. Each prism has the effect of rotating the pictures in the film gate through

90°, but with a small upward deflection in the one case and a downward deflection in the other. These deflections are compensated by chromatically-correcting prism-wedges, which are

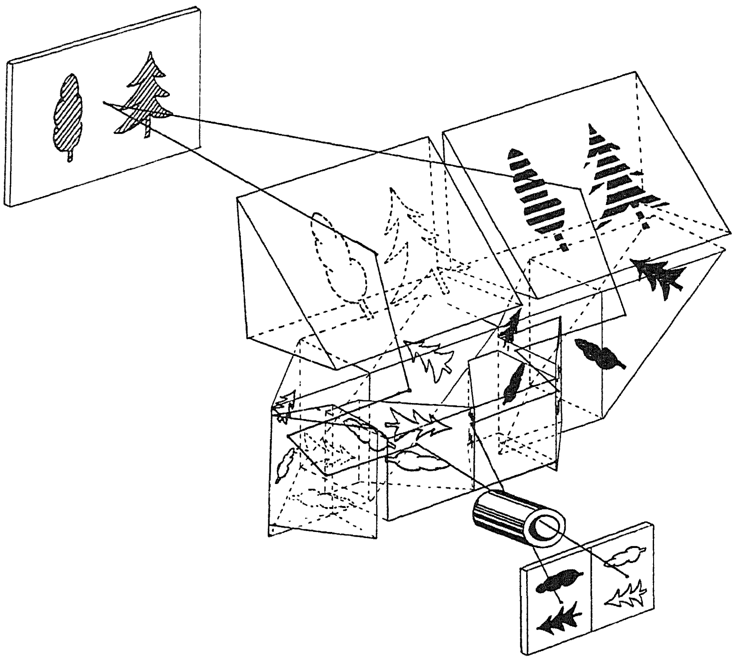

FIG. 42. *Beam-Splitting System: 'Similar-Sense Rotation' Type.* The 'scene' (or screen) on the left faces two 'forward-accepting' prisms whence the rays proceed downwards to two 'side-throwing' reflecting surfaces (both in same direction) to two 'back-throwing' reflecting surfaces, the picture now being rotated. These two left- and right-eye pictures, at interocular spacing, are now collected by a side-by-side Beam-Spreader and passed through the lens to the (split) film frame on the right.

semi-circularly shaped to fit the housing; the whole unit-lens, rotating prisms and correcting wedges being calculated for one particular set of projection conditions, for which the tilting preset screw on the rotating prisms acts as a fine adjustment. Convergence is in fact fixed and not variable. Included in the housing is a pair of polaroid filters of semicircular shape with axes of polarization set at right angles, mounted together in a

circular disc at the 'output' end of the device. The unit is thus complete in itself and self-sufficient. It is believed that the original intention was to photograph the films for these projection units with a single camera in which the normal lens would be substituted by a twin-lens panel, similar to the 'Stereotar',

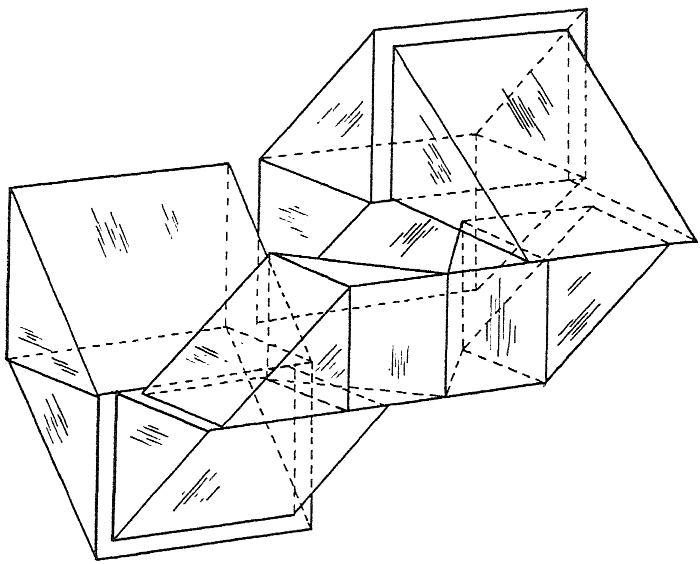

FIG. 43. *Similar-Sense Rotation Beam-Splitting System.* Schematic of an alternative layout to that in Fig. 42. The two identical sets of 3-unit prisms, seen at the front, transmit the adjacent head-to-tail pair of images lying on their sides through the two contiguous prism-faces in the middle to the film, each set having received and rotated in the same sense the incoming rays, the one from its third prism at the top and the other similarly from that at the bottom. The accepted 'scene' rays are received by 'input' faces (*at the same horizontal height*) of two rhomboid pairs of prisms, seen at the back.

but in which an additional prism attachment would provide the necessary rotations. In the event, however, it would appear that the two pictures were probably obtained by a two-camera method, being subsequently rotated and combined 'head-to-tail' in each frame of the show-copy film by a standard type optical printer.

A Similar-Sense rotation system due to the writer achieves

substantially the same final answer on the film by a single attachment which can be bracketed to any camera, the same attachment also being used for projection if the film is of sub-standard size. These attachments are in effect a combination of the basic 3-prism rotator and a ' beam-spreader '. If we took two left-

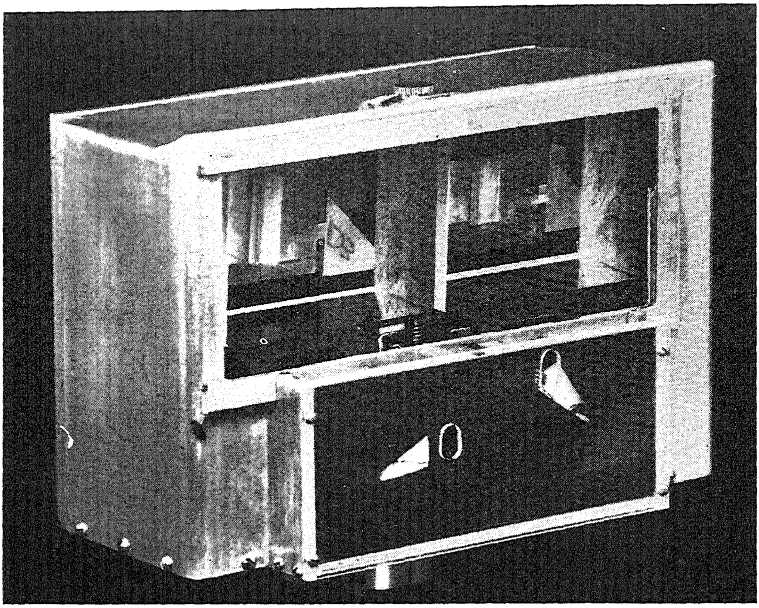

FIG. 44. *Similar-Sense Rotation Beam-Splitting System.* The Attachment which brackets to sub-standard 16 mm. or standard 35 mm. ciné cameras in conjunction with any of the normal range of focal-length lenses of either. It is subsequently bracketable to any sub-standard projector for screening the single film so photographed. A similar-sense version of the scaled-up opposite-sense projector attachment seen in Fig. 46 is used for projecting 35 mm. film. The convergence control is seen at the top and the focal-length pre-set controls at the front. The Attachment is also used for live and ciné T.V., as described in Chapter 9. (*Crown Copyright photo.*)

halves (or right-halves) each of three constituent unit prisms, off two of the opposite-sense attachments and placed them in front of the ' exit ' apertures of a vertically-side-by-side beam-spreader fixed to the camera lens merely to give us the necessary ' effective ' lens spacing equal to interocular distance, we should

be collecting two correctly spaced left- and right-eye views of the scene to be shot, rotating each of these in the same sense through 90° and passing them, after reflection inwards to the beam-splitting pair of prisms in the beam-spreader, to record two half-images head-to-tail on the film. Each of its outer pair

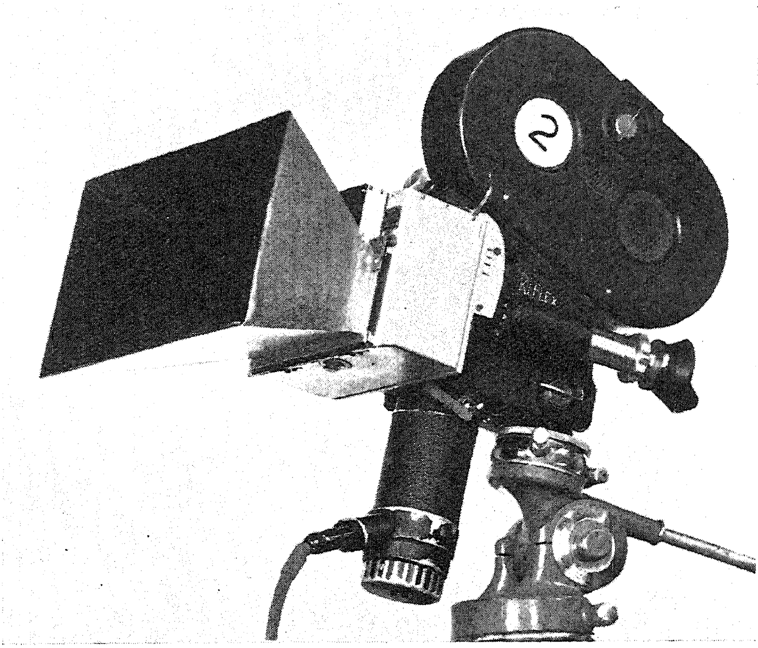

FIG. 45. *Similar-Sense Rotation Beam-Splitting System.* The Attachment, with 'lens' hood, shown bracketed to an Arriflex 35 mm. ciné camera. (*Crown Copyright photo.*)

of three 'image-rotating' prism units in these Similar-Sense attachments is fitted with the same type of prism-dipping convergence toe-in movement which is a feature of the writer's opposite-sense rotation system. In both systems, incidentally, a further movement is provided which permits the attachments to be instantaneously preset for use with any of the interchangeable camera lenses, within the normal range of focal lengths, or with any projector lens.

An interesting system, produced by SOM-Berthiot in their

'Stereo-Cinor' for 16 mm. film, combines the concepts of similar-sense rotation with that of a variation on the twin-lens theme. The camera assembly consists of a pair of the firm's proprietory standard 'Cinor' $f/3 \cdot 5$ lenses of 35 mm. focal length which are placed side-by-side in front of two rhomboidal

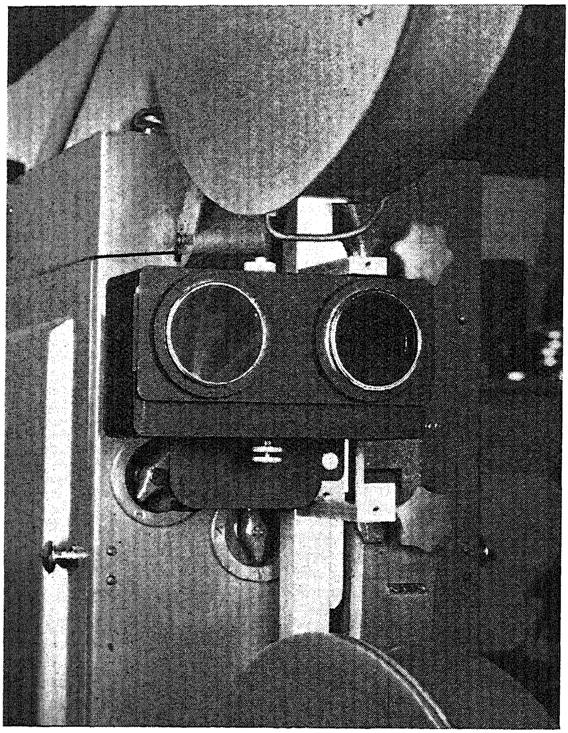

FIG. 46. *Opposite-Sense Rotation Beam-Splitting System.* The scaled-up version of the Universal-type Attachment, fitted with Polaroid Filters, shown bracketed to a G-B Type N 35 mm. ciné projector. (*Crown Copyright photo.*)

prisms of the vertical beam-spreader type which place the images, passed-on and formed by the Cinor lenses, side-by-side on one frame of the 16 mm. film; the image axes being 5 mm. apart so that, as in the Bolex system the space in front of the film is virtually divided into two 'cameras'. In front of the Cinor lenses, which are relatively close together, are placed the

two rear elements of the firm's standard focal type ' Hypercinor ' wide-angle lens attachment. Between these rear elements and the corresponding front elements, offset at 70 mm. apart to give an ' interocular ' pick-up, are placed two sets of three prisms, similar to the basic triad of the rotational beam-splitters described earlier on, which impart the necessary rotation to place the final images, via optical trains through the ' two cameras ', sideways-up on to a single frame of the ciné film, the same way round in the same ' sense '. The equivalent focal-length of the assembly is 18 mm. giving a field-of-view for each of the pair of images roughly the same as that of a standard 25 mm. sub-standard 16 mm. ciné lens. Provision for a scaled variable convergence has not apparently been made but the rear prisms can be given a slight shift to enable close-ups to be taken. There is, as in systems of the beam-splitting type, a quoted loss of light amounting to one stop, due to absorption in the optical train of each image.

CHAPTER VII

DISTORTIONS AND OTHER ANCILLARY CONSIDERATIONS

KEYSTONE DISTORTION

IN analysing any stereoscopic projection system with a view to ascertaining its relative merits, it is of considerable importance to investigate the effects of any *keystone distortion* that may be present in one form or another. As its name implies this form of image distortion arises, in taking or projection, if a rectangular framing is reproduced at the other end of the optical system with two opposite sides of unequal length: reminiscent of the shape of the 'key' stone supporting an arch in the middle. For example, if in projection the screen is not parallel to the film in the gate, it is not difficult to see that the image of the rectangular gate on the screen will be keystone-distorted with, say, its enlarged edge at the top and the diminished edge at the bottom when the top of the screen is tilted away from the projector. Similarly in taking, if the camera and consequently the film are tilted up and back away from the scene, the image recorded on the film will be keystone distorted; constituent objects in the bottom of the scene being laterally enlarged in their images at the top of the recording film frame. The mechanism of this conception is easier to visualize perhaps if the 'scene' in this case is thought of as being its reproduction, in the shape for example of a 'giant' photograph on a vertical plane at right angles to the line of sight. It should be noted further that a scene taken in this way and keystone-distorted in this particular direction can be corrected in projection by tilting the projector up and back away from the screen (thus, with light-rays reversed, re-establishing the exact taking conditions) or by tilting the top of the screen forward by a corresponding amount.

This *lateral* keystone-distortion has its counterpart, as we have seen in an earlier chapter, in the distortion in *depth* which is of a keystone shape if considered as viewed from the ' side ' at right angles to the line of sight. Such depth distortions cannot by their very nature be real in the objective sense to monocular apprehension on a two-dimensional flat screen, but can be considered as taking on subjective reality in the ' mind's eye ' when viewed binocularly as vertical images in effect. It is important to remember these distortions in depth, which arise in viewing projected stereoscopic pairs when the convergence in projection and/or viewing differs from that of the photographed original scene, when considering the somewhat analogous distortions in width or height about to be discussed; the point being that any distortion, either in a plane at right angles to the line of sight or in depth, should in any case be avoided for preference but, in comparative assessments between projection methods, an informed conception of what the relative consequent deficiencies that follow faulty projection in the two cases can be is essential in true comparative assessment between the various projection methods.

As the incidence of lateral keystone-distortion depends upon non-parallalism of film and ' scene ' or screen in effect, this drawback cannot be fundamentally inherent in two-projector or alternate-frame types of projection. This is not so, however, in true beam-splitting systems; that is to say in those systems in which the angle-of-view is split in two adjacent halves. Let us therefore rapidly review the various beam-splitting systems and see to what extent this distortion limitation occurs and whether or not it should be, and can be, cancelled out.

Vertical, Side-by-Side Types

Taking first the side-by-side vertically split unrotated systems, of which the Stereoloy and the Stereo-Tach could be typical, let us examine what it is we are really doing when splitting the beam. Imagine for a moment the taking camera without its beam-splitting attachment. The lens is accepting a horizontal sweep, whose angle-of-view is say $\theta°$, which just covers the width of the film frame in the camera. If now the attachment be bracketed on in front of the lens this angle-of-view will be

split, by a vertical plane passing from the camera lens through the middle of the scene, to give two equal half-angles-of-view of $\theta/_2{}^\circ$ equally distributed on either side of the central dividing line. These two half-angles impinge on the two halves of the film; and it is important to notice that this central plane-of-vision is perpendicular to the plane of the film. This means that the rays forming the inner boundary-edges of each half-image are also falling perpendicularly on the film. Normally, however, when recording or projecting an image, it is the centre ray of a beam that is at right angles to the film, just in fact as it was for the unsplit full-frame image before we interposed the beam-splitting attachment in front of the lens. Furthermore, when we come to project these images it will be a ray central to, and at right angles to each half-frame, that will be thrown on to the screen centrally and perpendicularly. Thus if we do nothing more about it, the beam-splitting projector assembly will merge two half-pictures on the screen, both of which in recording have been 'keystone-expanded' away from the old common central division line; one expanding to the left and the other to the right. But the success of the stereoscopic illusion depends almost entirely on the complete superimposable identity of the two merged half-frame images, excepting of course for their essentially disparate nature. In this case therefore the fact that our two half images are distorted in opposite directions militates against the 100 per cent. illusion of real depth.

Corrective Methods

There are, in general, two methods of overcoming lateral keystone distortion when it arises. The first of these is to shift sideways—using the side-by-side illustration above as an example the two projectors, or the two effective beam-split objective-apertures in the case of one projector—one to the left and one to the right, so that the rays from the image points at the common split dividing line in the recorded image are projected to fall perpendicularly on the screen, in this way exactly reversing the original taking conditions. Thus a cure here can be obtained if the screen is say 4 ft. wide, by spacing the two projectors, or the two 'exit' apertures of the beam-splitter of one projector, by this same distance 4 ft. instead of by the normal $2\frac{1}{2}$ in.,

thereby ensuring that the appropriate side boundary rays reached the screen at right angles from the projector apertures placed exactly opposite in front. An alternative method of

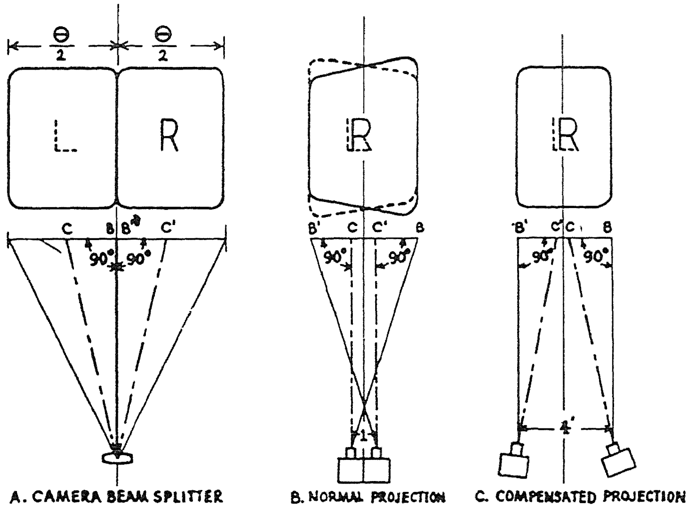

FIG. 47. *Keystone Distortion in 'Vertical' Side-by-side Beam-Splitters.*
(A) In taking, beam-splitter divides the angle of view in half, and the angle at B and B' is 90°.
(B) In normal projection, however, centre angles C and C' are 90°, causing Keystone Distortion.
(C) To compensate, the width between projectors is made equal to the screen width, thus angles B and C' are once again 90°.

correction, that of tilting either the film or the screen to correct for the initial beam-splitting 'shift' in the axis of the halved angle-of-view, is inapplicable in this particular case as it is not of course possible to tilt either the film in the gate, or the screen, in two opposite directions at one and the same time.

Two-Projector and Twin-Lens Systems

It has already been remarked that two-projector systems of stereo projection can be immune from this type of keystone-distortion, and it is to be noted that the same freedom is shared by twin-lens systems. Twin-lens systems convert in effect the existing camera into two separate cameras working side by side on the two halves of one film. Were it not necessary, in order

to record a ‘ normal ’ parallax, that the ‘ stance ’ of the twin-lenses should be such that the operative distance between the lenses should be equal to the interocular distance, this substitution of the original single lens by a twin-lens panel would be all that is necessary and sufficient. It is by the addition of a ‘ Stereoly ’ type beam-splitter—what we have called to avoid misconception a ‘ beam-spreader ’—that the increased effective lens-separation is provided, but this is its sole function in such an application as this. For, whereas a beam-splitter, used in conjunction with a single lens, splits its angle-of-view into two; used with two lenses side by side, it can merely provide each lens with a laterally adjustable view-point. In such circumstances it is clear that no question of keystone distortion should normally arise in a twin-lens system. This could be inferred anyway from the fact that all reflecting surfaces involved are normally at 45° to scene, film and screen in ‘ parallel ’ taking and projection and all rays proper to the centres of the two separate angles-of-view of the two lenses are at right angles to these same three planes.

Rotation Beam-Splitters, Opposite-Sense

There remain the ‘ rotational ’ types of beam-splitting systems to discuss in connection with lateral Keystone Distortion. Taking the two types of system in turn and that of the Opposite-Sense rotation first we can, by tracing rays through the system, deduce what keystone distortion will take place. If we imagine an attachment of this type bracketed in front of a lens, the bottom horizontal edge of the scene being recorded will be caught by the bottom back edges of the top pair of ‘ down-throwing ’ prisms and thrown on to the inner edges of the ‘ side-throwing ’ prisms and thence to the vertical inner edges of the central pair of beam-splitting prisms back through the lens to form the parallel inner edges of the two images on either side of the vertical boundary line dividing the full frame of the film into two halves. This is known as ‘ tail-to-tail ’ recording. The rays we have traced out are those central to the full camera frame and impinge on the film at right angles; which they should. With all the reflecting surfaces of the attachment kept at 45°, however, the corresponding incoming rays to the attachment will, unless

the attachment be otherwise adjusted, be horizontal and strike the scene (imagined as a vertical photographic replica for convenience) perpendicularly at the horizon. In practice, however,

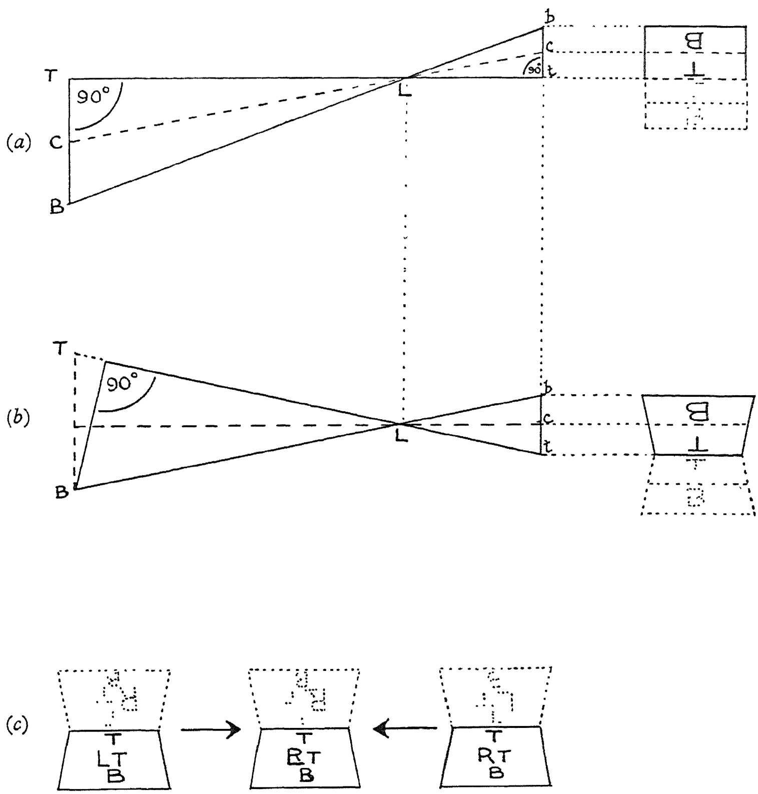

FIG. 48. *Beam-Splitting, Opposite-Sense: Keystone Distortion* (much exaggerated). As explained in the text, (*a*) and (*b*) show how keystone distortion arises in necessarily tilting the prisms to align the two half beams horizontally. In (*c*) the effect of subsequent superimposition of the two half frames is shown.

a camera so lined up that it photographed only that part of the scene which was above the horizontal would be unpractical. For this reason these top prisms are given a permanent tilt downwards of a few degrees (actually $\theta/4$, where $\theta°$ is the angle-of-view vertically of each half of the attachment) so that it is

now the central ray of the top prism that impinges horizontally, thus spreading the available angle-of-view equally on either side of it, top and bottom. But the bottom rays should impinge on the plane of the scene at right angles if no distortion is to arise. In fact the plane of the screen is of course vertical and is therefore at an angle of $\theta/4^\circ$ to that cross-sectional plane of the angle-of-view which is at right angles to the bottom component ray. Seen through this cross-section, the bottom of the scene, viewed ' further away ', will be shortened as compared with the top owing to the consequent ' compression ' effect on included objects apparently more remote. As recorded on the film, the tops of the half-images will be wider than the bottoms which are contiguous at the middle of the frame, and thus display the effect of two keystones with their narrow sides adjacent. On superimposition on the screen, however, these two keystones will be oriented in the same way, i.e. a resultant picture slightly wider at the top than at the bottom. If thought necessary, this can easily be corrected by a slight tilt of the screen backwards from its top and away from the projector. (Alternatively the projector can be tilted forwards, or the projector can be raised slightly above the level of the screen.) The important thing to notice nevertheless is that, since we have two identical half-frame distortions which are precisely superimposable, there is no need for any correction, if we are concerned only in the efficiency of resolving the two half-frames into a convincing stereoscopic picture and in ensuring the absence of fatigue or strain in viewing. Correction for keystone distortion in Opposite-Sense rotation systems is thus only necessary if the ' drawing ' of the projected result on the screen must be truly rectilinear.

Rotation Beam-Splitters, Similar-Sense

In discussing the incidence of keystone-distortion in Similar-Sense rotation systems, it will not be necessary to trace out again the paths of the ' key ' rays. If we remember that in this system we are employing two precisely similar halves taken from two Opposite-Sense rotation units, one of which is turned through 180°, it follows that ' head-to-tail ' recording must ensue and therefore that the same keystone-distortion pattern

as before, acting upon this new relative disposition of half-images instead of upon that of the old tail-to-tail, is bound to give a different final result. We may indeed say straight away then that when projected one half-image will be keystone distorted narrow-side up, whereas the other will be distorted narrow-side down. In superimposition on the screen two such half-images, distorted as they are in opposite directions, are bound to show, over considerable areas, departures from that complete identity which they should have apart from their necessary ' disparity '. In such a case, the mental effort of

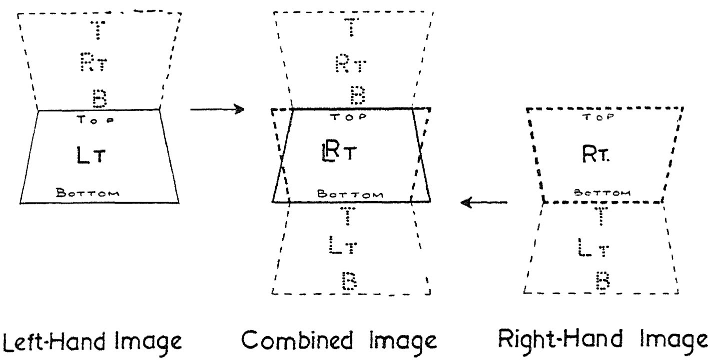

FIG. 49. *Beam-Splitting, Similar-Sense: Keystone Distortion.* As explained in the text, the superimposition of two left- and right-halves of beam-split pictures, rotated in a similar sense, gives rise to unsuperimposable half-frames distorted in opposite directions.

integrating an illusion of solidity from the disparity of two half-images which are slightly out of register could theoretically be abnormal and conducive to some strain or fatigue in prolonged viewing sessions. In practice, however, it is found that any ill effects there may be of this type due to ' contradictory ' keystoning are not noticeably disturbing, at least if projected on a comparatively small screen. If the effects are accentuated when projection takes place on big screens, which could be open to doubt in the absence as yet of protracted large-scale tests, and their correction-out in such circumstances or in any others where the highest standard in precision projection are required for professional purposes, this contrariwise keystoning can

nevertheless be eliminated. Of the two methods of correction, that of tilting the screen or the film (unless two projectors and two films are used) is inapplicable, as it is not possible to tilt either in two opposite directions at the same time. In the second method, however, the distortions can be counteracted by the artifice of displacing vertically the two projector apertures concerned, one up and the other down, from the horizontal plane containing the middle of the screen. The amounts of these required displacements can be readily calculated by making use of a guiding criterion which would state that ' the recorded distortion on the film will be eradicated on the screen if the top ray from the bottom aperture and the bottom ray from the top aperture both pass through a point in space which the camera lens would occupy if this camera lens (with its different focal length) were used to project the same picture on the same screen, same size '.

ANCILLARY CONSIDERATIONS

Vignetting in Beam Splitters

We have now reached a stage where it is possible to review certain important ancillary considerations which may have a bearing on the success or otherwise of stereoscopic projection. Some are restricted to one or more projection methods; some are universally applicable. The first to be considered concerns only beam-splitting devices. It is that of the relationship that may subsist between the proximity of the lens to the beam-splitter, the vignette width and the maximum lens-aperture stop available. The angle-of-view and the focal length of the lens concerned are the determining factors in this relationship, but as the maximum value of the angle-of-view will have been determined once and for all in designing a beam-splitter to cater for that of the lens of the widest angle intended to be used, we may regard angle-of-view as a fixed quantity in our survey. There is also a limitation to be considered which is presented by the actual physical depth of the mount of this particular lens which prevents the attachment being brought up closer than to a certain minimum distance. Our only problems therefore are to determine to what extent we may space out the attachment from this limiting minimum distance, and/or otherwise adopt masking

or similar measures to the end that the maximum available aperture and the minimum vignette width, or both, may be encompassed. If we cause the beam-splitting prism to recede somewhat from the lens, it should be clear that the prism fails to cover any longer the peripheral rays of the angle-of-view cone that a given lens subtends. This cone (for objects at a

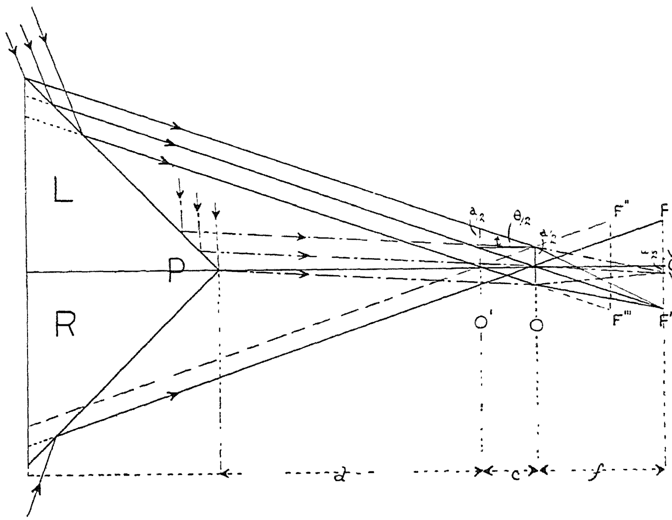

FIG. 50. *Effect of Camera-Lens Aperture on Beam-Splitter Film-Coverage.* The lens at O, half-aperture $a/2$, accepts rays from the left side of any beam-splitting device, LP, focussing these at the film edge F'. It is obvious that $(d + c)$ is the maximum distance of the beam-splitting edge P from lens O, that will ensure full coverage to edge of film, for the particular prism size and aperture of the example; as a reduction of the distance, by, say, the amount c in moving the lens to O' to give a value of d, demonstrates—the beam-width accepted at the prism edge being reduced by half.

considerable distance as compared with the focal length—which they always are) can be considered as being made up entirely of parallel beams, each beam corresponding to one particular point in the image, the cross-sectional width of which is that of the aperture stop of the lens. If, in moving the attachment further away, the lens now fails to embrace the whole width of the peripheral beams on the outside of the cone, it can only mean that the working diameter of these beams, and consequently the effective diameter of the lens aperture stop, have been

reduced. On the other hand, the width of the central half-image dividing line vignette is dependent upon the ' spill-over ' at the apex of the prism of rays into the ' wrong ' half-picture. An attachment further away from the lens will cause the central beams to take up an even shallower angle from the spill-over boundary on the prism (which is situated at the width of the aperture stop away from the apex) to the lens, and consequently therefore from the lens to the centre of the film, thus reducing the objectionable vignette width. Since a movement to or fro of the prism with respect to the lens can only effect a desired improvement in one or other of maximum aperture and vignette width, it is necessary by calculation or experiment to determine an optimum distance at which to fix the prism in front of the lens to give an arbitrarily chosen acceptable standard of performance of either, or to adopt other subsidiary means to give optimum conditions of both.

The formation of vignettes can be considered as being of two kinds. Either the line of demarcation is expanded in width to form a black area of ' absence-of-image ', or the edge of each constituent half image spills over into the ' wrong half ' thus leading to ghost images on either side, superimposed upon the wanted legitimate images.

In Fig. 51 the right-angle beam-splitting edge *BAC* is shown which is typical of the beam-splitting edges which have been described.

Light incident from the scene being photographed on the left and right input prisms of the device, which are not shown to simplify the diagram, will arrive at the two faces *BA* and *AC* from opposite lateral directions. A parallel beam incident at 45° to the face *BA* at the apex of the beam-splitting edge is shown which, after reflection, passes through the half aperture $a'/2$ at N' of a lens, focal length $N'P'$, whose focus is at P'. It will be clear that further rays in the incoming beam incident upon the face *BA*, whose angle of incidence to the reflecting face is greater than 45°, will be reflected in a similar way but will be, in major part, accepted by the whole aperture a' at N' of the lens concerned to form a legitimate half image at P', somewhere on the film at the under side of the Figure. If, however, a ray *R* is incident at the apex of the reflecting edge at an angle, as shown,

greater than 45° this ray, although appropriate to the other half image and normally reflectable from the other face *AC* of the beam-splitting pair of reflecting faces, can yet pass through the aperture *a′* at *N′* of the lens to form a ghost image at *P′* on the upperside of the film of the diagram. The particular ray *R* is the limiting ray of all those rays properly belonging to the other half image, and lying between *R* and the parallel rays shown,

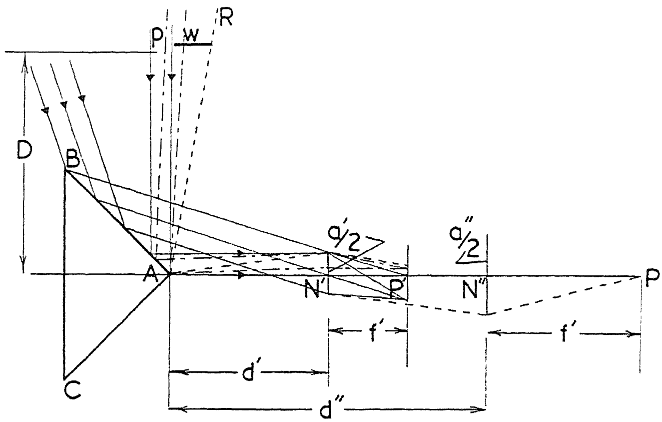

FIG. 51. *Effect of Camera-Lens Aperture on Beam-Splitter Vignette-Width.* As explained in the text, the introduction of a Mask of variable width at, say, *w* can cut out ' ghost ' images appearing in the ' wrong ' half-picture on either side of the dividing vignette.

which will be so accepted by the lens to form ghost images in the wrong half at the other side of the line dividing the film into two.

In such circumstances we can employ a mask, at some such position as that schematically shown in the diagram at *w*, to cut off all these ghost-forming rays whose angle of incidence is greater than 45°. The width of the mask required is clearly dependent on the physical width of the aperture of the lens actually in use at a given time, and upon its focal length and its distance away from the apex of the beam-splitting edge. Means can therefore be provided whereby an opaque mask of sufficient width is variable in its location position so that its working edge *P* may be such that all rays exceeding 45° of incidence at the reflecting beam-splitting edge concerned are just obscured

sufficiently as dictated by the geometrical relationship requirements of lens aperture, lens focal length and distance of lens from the apex of the beam-splitting edge.

Light Loss

In all systems of stereoscopic projection, the efficiency of screen illumination is of first importance. In the first place, let us take the four types of stereoscopic projection: Two-Projector, Alternate-Frame, Beam-Splitting and Twin-Lens. In the two-projector method we are simultaneously throwing on the screen separate left- and right-eye views, the whole merging to give, we will assume, an equal subjective impression of resultant light intensity on the screen as that which was given by an imaginary equivalent ' straight ' two-dimensional shot. Clearly each of the two projectors must provide an illumination at the screen equal to that of the straight projector; for there is no evidence to show, except for very weak illuminations indeed at the ' threshold ' of vision, that the screen brightness due to the two projectors, as seen by the two eyes separately, are additive. In consequence, the ' two-projector ' method can be considered as suffering a light loss of $\times$ 2. In the ' alternate frame ' method, however, owing to the fact that by doubling the film speed each eye sees precisely what it saw before in the equivalent straight projection, there is no intrinsic light loss and the factor is $\times$ 1. In beam-splitting systems, or in fact any system where the normal ciné frame is divided into two, a beam-splitting light loss factor of $\times$ 2 becomes operative for the reason that each side of the lens associated with the beam-splitter tends to throw the complete image of both halves, of which only one half in each case is projected on the screen. Twin-lens systems are more difficult to assess. Where projection, as in the Bolex system, is dependant on a twin projector lens, each lens constituent is projecting its own half-image at its own rated aperture. Using a film gauge of 16 mm., such apertures can be relatively high and comparable with those single lenses used in normal 'straight' projection. A similar system employing the standard gauge of 35 mm. would, however, experience difficulty in 'twinning-up' two lenses of lenses of the relatively large physical aperture-size usual in theatre projection whilst yet retaining an axial

separation of the order of half an inch only. In consequence, we can at best generalize by saying that two lenses packing into the space of one would, in the limit, have effective working aperture of half the normal 'straight' lens, giving a light loss factor of $\times$ 2.

Let us now examine what the incidence of the use of Polaroid as a viewing aid may be on any of these systems. When a Polaroid filter is used, half the light (50 per cent.) in the plane of polarization at right angles to that which it is 'set' for will inevitably be lost. The filter transmits, even in the plane for which it is set, only some 40 per cent. of the incident light. The 'transmission loss' is therefore $50 - 40 = 10$ per cent. If this same transmitted light polarized in one plane be passed through a second filter set in the same plane of polarization, a further 10 per cent. would be lost only; i.e. the second and subsequent filters pass 90 per cent. of the light in their own plane. Taking now a typical Polaroid viewing-aid set-up, it will be seen that of the incident unpolarized light at each of the left- and right-eye sides of the projection system, a light transmission factor of 0·4 (40 per cent.) applies at the projector polaroid and a further 0·9 (90 per cent.) factor at the viewing-eye filter. The total light transmission due to the use of polaroid in projection and as a viewing aid is therefore $0{\cdot}4 \times 0{\cdot}9 = 0{\cdot}36$, roughly a third of the incident light. Combining these values with those previously deduced and appropriate to the four methods of projection, we get the following fractions for the effective light passed by each. 'Two-projector': $\frac{1}{2} \times \frac{1}{3} = 1/6$ (or alternatively $1 \times \frac{1}{3} = 1/3$, provided that the necessary doubling up of projectors is otherwise taken into account); 'Alternate-frame': $1 \times \frac{1}{3} = 1/3$; 'Beam-splitting': $\frac{1}{2} \times \frac{1}{3} = 1/6$; 'Twin-Lens': $\frac{1}{2} \times \frac{1}{3} = 1/6$.

Definition

It has already been indicated that the final *definition* apparent to the eye when pictures are projected on the screen by the various systems, is of considerable importance and a factor to which weight must be attached in assessing their relative merits. In the first place we have seen that the major appeal of the two-projector and the alternate-frame systems lies in their retention

of a definition theoretically equal to that obtained in ' straight ' two-dimensional projection due to retention of the full frame, whereas in the beam-splitting or twin-lens systems there must be a fundamental halving of the resulting definition owing to a halving of the previous ' straight ' area into which photographic detail can be packed. Theoretically also there could be a loss of definition in beam-splitting and allied systems owing to light-scatter within the optical units comprising the attachment, which does not arise in the other two types of system. Given good optical design, however, such losses can be negligible in practice. A major source of loss of definition, applicable to all systems if a viewing aid of the polaroid type be used, lies in the polarizing material used in the filters and in the optical finish of the containing glass. In the case of the glasses worn for viewing, owing to their close proximity to the eyes, the ordinary ' B ' type glass mounting suffices, but for the filters used at the projector it is essential that the glass mounts should be optical flats and that they should be coated.

Colour Correction

When ciné pictures have been taken on sub-standard mono-pack colour stock, the projector illuminant should normally be that of the ' tungsten ' light of the usual projector bulbs, as processing by the manufacturer of the film will have been carried out specifically with illumination of the colour temperature of tungsten lighting in view. Thus the colour balance obtained with the normal 16 mm. projector lamps will be found as satisfactory as it is in straight projection. Should, however, beam-splitting or other systems employing substantially more glass than the normal camera lens have been used, compensation can be made if found necessary for the coating on the reflecting surfaces of the additional glass which can, both in taking and projection, impart a slight overall yellowish tinge to the picture. A pale blue filter fitted to the camera taking attachment will not appreciably affect the exposure and can be chosen of such a density that it compensates, not only for the coating of the taking attachment, but for that of the projector attachment also in subsequent projection. If as is likely in standard 35 mm. practise an arc illuminant be substituted for tungsten lamps in projec-

tion, the colour temperature of the light can be corrected by a yellow filter. For preference, to preserve the filter from the heat of the arc, these should be preceded by heat-dissipating filters.

CHAPTER VIII

THE 3-D OF TO-DAY

THE year 1953 will not easily be forgotten, if only for the bursting of the ' 3-D ' bombshell upon an ill-prepared and astonished world. The growing mass-audiences of Television and the consequent decline in the astronomical attendance figures in the ' legitimate ' cinemas of the world had triggered off a ' spontaneous ' appearance of a panacea for all ills in a resuscitation of the dormant ' true ' three-dimensional stereoscopic projection following upon the invention of the new forms of *wide screen* two-dimensional presentation, ' Cinerama ' and ' CinemaScope '.

WIDE SCREEN 3-D

A spectacular innovation in the mid-1930s had been, at a few selected West End or Down Town super-cinemas, of a *wide-screen* two-dimensional presentation on the ' Magnascope ' screen. Usually the form of film which exploited the novelty was of the ' big-spectacle ' variety and at a critical and appropriate moment in the story the curtains bordering a screen of the normal shape were drawn wider to disclose a panoramic extension of the picture that had simultaneously been faded in. In two films shown in London—' Chang ' at the Plaza and ' King Kong ' at the Coliseum—the entertainment began and ended on the central part of the screen of normal size and proportion, the full screen at its widest only being used for the spectacular sequence in either case.

In contrast the earliest of the new wide-screen films to be seen have consisted of nothing more than the projection of a film, shot for the normal width of screen, which has been projected with a lens of wider angle of throw so that it could embrace

a wide-angle on a screen of greater width than the normal. Inevitably the top and bottom strips of the projected frames were cut off, whilst the definition had deteriorated in the ratio of the new width to the old. These so-called ' wide-screen ' methods of projecting normal angle films were presumably only intended as a stop-gap until such time as films made and projected by methods based on true wide-angle principles could be developed and produced.

Wide-angle, Wide-screen

The use of a wide screen logically implies projection upon it of a wide angle picture ' to suit '. Otherwise, as described above, a wide screen can be ' filled ' only by an inordinately long decapitated picture of degraded definition and distorted perspective. It is presumably neither the future policy intention of the major companies to present such films nor the inclination of sophisticated audiences indefinitely to sustain them. ' Wide-screen ' of the immediate future must therefore be synonymous with the projection of wide-angle films. Existing examples of such projection methods are ' Cinerama ' and ' CinemaScope ' and there would appear to be no alternative in wide-angle projection to the adoption of variants of one or other of the methods used by these two systems by would-be wide-angle film producers. The first employs the method of side-by-side projection of three separate pictures, so taken; the second expands in projection a picture compressed in taking by means of special lenses containing astigmatic components. The trend of wide-screen systems-to-be can therefore best be gauged from a detailed description of these two pioneers.

Cinerama

' 3-D ', in its topical sense, can be said to date from the first public performance by the Cinerama (*cine*ma pano*rama*) system at the Broadway Theatre, New York City on September 30th, 1952; a system owned by an independent company, of which Mr. Louis B. Mayer is chairman, and invented by Mr. Fred Waller.

This spectacular conception frankly sets out to provide all the possible ingredients that go to make up what the eye sees and the ears hear. The basis of the system is the projection, from

three projectors displaced 48° apart around an arc facing the screen, of a triptych of married pictures side by side upon a huge concave screen, six times larger than the normal, 64 ft. wide by 23 ft. high. Eight loud-speakers disposed at strategic points in and around the auditorium and fed from six sound tracks recorded on a single magnetic tape reproduce the sounds picked up by six separate microphones similarly disposed around the scene of action that has been shot simultaneously by the three cameras.

The screen, which is flat in the centre for showing alternative normal films, covers an arc of 146° and spreads across some 50 ft. at the proscenium of the theatre. To obtain even illumination over the auditorium, the screen is made of 1,100 vertical strips of tape separately disposed at appropriate angles to serve this end.

The added visual perception which the system sets out in particular to recapture is that of ' peripheral vision '—the unconscious observation which occurs in real life of a much wider scene than one is conscious of seeing—seeing out of the ' corner of the eye ' in fact. There can be no doubt that the illusion of reality which Cinerama sets out to capture is certainly achieved in considerable measure, whether this be due to a real contribution to peripheral vision or merely to the wide angle, and the results are impressively spectacular. Roller-coaster, motor-boat and aeroplane hedge-hopping rides are realistic to the extent of arousing similar reactions in the audience to what the real thing would cause. ' Travelogues ' too are considerably enhanced in realism and interest, whilst the reproduction of large orchestras uses to the full, and at its best in this context, the three-dimensional ' feel ' of the ambitious panoply of stereophonic sound.

CinemaScope

This prominent variant of wide-angle technique, adopted by Twentieth Century-Fox, is based on the use of a special lens, the Anamorphoser—the invention of M. Henri Chrétien. The system, deriving from a much earlier one in France known as Anamorphoscope, uses a particular form of anamorphic lens, to compress the image parallel to the vertical on the film in the

camera when photographing the picture and subsequently to re-expand it on projection. The word 'anamorphosis', derived from the Greek, has for one of its meanings that of 'a distorted drawing which appears undistorted from a particular point'. If we picture to ourselves an image on the film in the camera which has retained its normal height, but has been compressed inwards horizontally from each side—'squashed', as it were—then we can in our imagination see that, at two points top and bottom in front of the frame, lying in a vertical plane through the middle of the picture, there will be viewing stations from which the compressional distortion actually recorded on the film will appear to be equalled and thus nullified by a compensating distortion of compression due to the angle in the vertical plane at which the picture is now seen 'on the slant'. A precisely similar phenomenon is an every-day experience to road users when, for example, they approach the grossly elongated letters HALT painted on the road which, from the slant angle of view of a considerable distance away, are recompressed vertically to resume in appearance their normal shape proportions.

To present on what we have now come to call a 'wide-angle' screen a true wide-angle picture, we would need to use a wider angle camera lens than has, up to quite recently, been available. Wide-angle lenses in normal availability hitherto, have focal lengths of some 35 and 25 mm., the corresponding widest angle of view attainable with 'straight' lenses being therefore of the effective value of some $47\frac{1}{2}°$. Such lenses, especially the widest, have to be used with discrimination, because the 'drawing' of the corresponding picture on the screen, in the case of the latter for example, is only 'correct' as the camera saw it for viewers seated very near the screen, roughly a screen width away. Thus for the majority of the audience the projected scene can be seriously distorted in perspective, and is especially noticeable in 'panned' shots. A wider screen to take these wide-angle shots is an obvious solution, but to project on this wide screen would react unfavourably in the opposite direction for long focal-length or telephoto shots. Apart therefore from the incentive of introducing a 'spectacular' novelty into the motion picture theatre, the need outstanding

for a more elastic link-up between camera and theatre effective angles of view is apparent.

A wider angle of view than that hitherto attainable by straight lenses can be accepted if, after acceptance, the lens concerned can compress the picture laterally to 'fit' into the normal frame width. If subsequently projected by a normal lens the picture would of course appear to be still compressed laterally, unless the projected lens be modified to re-expand the picture

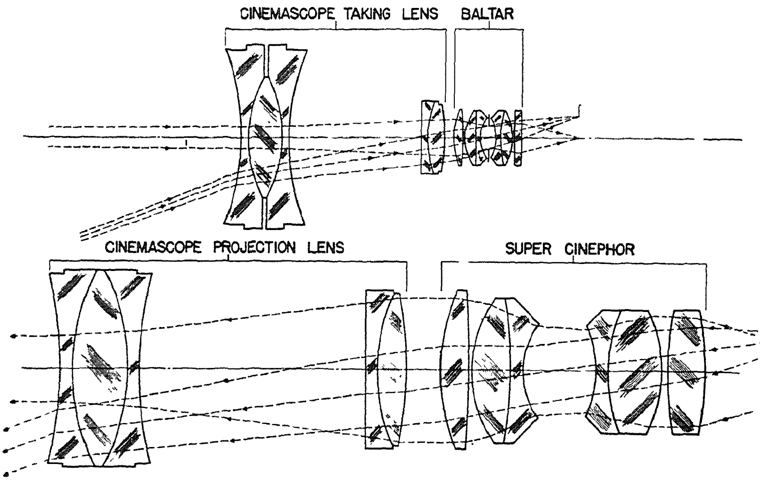

FIG. 52. *CinemaScope: Optical Systems.* (*Courtesy Carl Bausch.*)

back into its originally accepted proportions. This can be done by the incorporation within the lenses of astigmatic components of the cylindrical type; the correction for astigmatism in ophthalmic practise providing a loose parallel. The special feature of a cylindrical lens is that it 'brings to a focus' image elements lying in planes at right angles to its 'length', but has no focussing effect along it. Used by itself it would produce a line image. Cylindrical curvature components incorporated in the optical design of a lens can, however, achieve the half-way house of an otherwise normally undistorted image, which is yet compressed by a designed amount along one axis, but not along the axis at right angles. The characteristic property of anamorphic lenses is therefore one which enables them to form sharp

images with different magnifications in different 'directions' to, say, the vertical. Such designs are nevertheless extremely difficult to compute without introducing optical aberrations; the difficulties increasing with the degree of compression sought. Several forms of anamorphoser designed by different inventors have appeared, but it is the particular invention of Professor

FIG. 53. *CinemaScope: Camera Attachment.* (*Courtesy Carl Bausch.*)

Henri Chrétien, which effects a large compression without serious distortion, that has caught the flood tide.

In CinemaScope operation, the 'normal' camera lenses, of 50 mm., 75 mm., and 4 in. focal length, can be used in conjunction with the anamorphic lens system. Used with the 50 mm. lens, for example, the combination works, in effect, as a wide-angle lens of some 20 mm. focal length. In operation on the camera, the anamorphic combination requires a continuous

adjustment of the astigmatic optical component concerned to give the best approximation to sharp focus, depending on the scene details being taken.

Projection takes place upon a wide screen, of an approximate aspect ratio of $1:2\frac{1}{2}$, the screen being curved in the form of a cylindrical segment, axis vertical, and concave towards the audience. In a typical example, the radius of the screen would

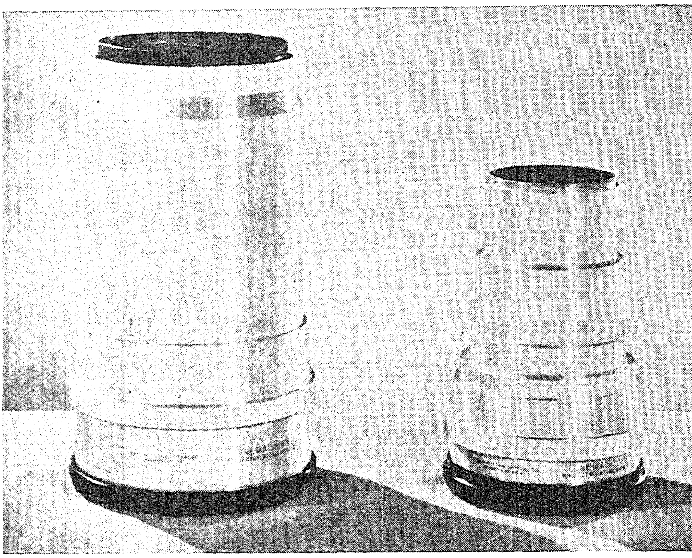

FIG. 54. *CinemaScope: Projection Attachments.* (*Courtesy Carl Bausch.*)

be some 140 ft., with the corresponding dimensions of $21\frac{1}{2}$ ft. in height by 53 ft. in width. On such a screen the projected picture would have the angular dimensions of some 60° vertically and 100° horizontally. For such a screen, which incidentally in recent CinemaScope practise is of an aluminium-embedded vinyl-acetate material, the arc-current consumption would be of the order of 80 amperes for adequate illumination.

The system will be used with a form of 'stereophonic' sound, read off three sound tracks recorded at the side of the single film. To obtain more room for the third track and to still retain the normal frame area of the picture, a new film

layout is being developed in which the sprocket holes will be 0·078 in. wide instead of the normal 0·116 in. Sprockets in existing projectors intended for conversion would therefore have to be changed but the existing sound-head box can be modified to cater for the third track; or where this is impracticable a special box can be fitted, without other change.

No depth impressions, such as those given by the binocular factors in ' true ' 3-D, are claimed for CinemaScope. The gain, which can be spectacular, is in the effective use of a wide screen; for in real life we are accustomed to a horizontal viewing span of 120° or more; so that the wider the presentation the more convincing the projected illusion is likely to be, and is what is meant by ' peripheral vision '. To what extent the curvature of the screen adds to effectiveness of peripheral viewing is doubtful as the amount of the ' bending round on either side ' which is operative for such of the audience as are in the middle or at the back of the theatre can only be negligible. Suggestions that depth impressions could conceivably arise and be attributable to a specious form of binocular vision in that with a curved screen the picture seen by the two eyes might not be quite the same, are probably illusory. It is believed in fact that the employment of a curved screen could be attributed entirely to the expediency of obtaining a reflected illumination which was approximately even over the greater part of the auditorium.

' TRUE ' 3-D

It was not astonishing, when the call came for a method of ' true ' stereoscopic three-dimensional projection, based on binocular vision principles, as an alternative to those wide-screen variants dependent upon the specious or, at most, partial ' three-dimensional ' phenomenon of peripheral vision, that a technique proved to be at hand which could be developed almost overnight into the efficient systems, sponsored by the major film corporations, capable of producing what was for most people a unique experience—their ' first ' 3-D film in *depth*.

This rapid response could not have come about had it not been for the devoted application of some few pioneers, during the previous decade or so, to the solution of the theoretical and

practical problems involved in two-picture stereo-projection; and would have proved impracticable but for the invention of Polaroid by Edwin Land. The geometrical theory of two-picture projection had been put on a firm basis by Professor Rule in 1941, whilst even earlier John Norling had demonstrated to millions at the New York World Fair in 1939 the entirely practicable nature of two-camera, two-projection methods of stereoscopic projection. It is indeed possible that, had it not been for the Second World War, commercial 3-D might even then have followed this lead. In the event, however, the next juncture at which a great number of people had the opportunity to appraise 3-D occurred at the Festival of Britain in 1951 when a series of 3-D 'shorts', using a two-camera, two-projector technique due to Dudley and Spottiswoode, was shown, together with large-screen Television, at the Telecinema at South Bank.

With such leads, two-projector systems were obviously strong candidates for adoption when the need for an alternative to 'wide screen' became imperative. Indeed, as it has turned out, no other system proved on investigation to be commercially applicable. Alternative single-camera, single-projector methods, whether of the alternate-frame, beam-splitting or twin-lens variety, were 'out' anyway if only on the grounds of light loss; existing projector arcs, even when boosted to a new and apparently maximum limit, being incapable of providing more than the extra light needed for polaroid viewing.

The immediate problems of the film producer wishing or forced to enter the 3-D field are therefore for the moment merely those of the adoption or adaptation of well-known and well-established equipmental techniques together with the investigation, usually by trial and error, of the means of conforming to the not-so-well established rules of stereoscopic cinematography dictated by the rigorous geometrical requirements of large-screen projection. More than one school of thought, and some additionally of practise, exists or has existed to guide or confound the would-be producer. By and large, however, the early work and reasoning of Norling and Rule have proved sound pointers to later and more elaborately based theoretical and practical investigations, such as that of Armin J.

Hill for the Motion Picture Research Council, which are capable of giving a reliable and effective lead to potential Presenters and Producers of an adequately *true* 3-D.

MOTION PICTURE 3-D IN REVIEW

Of the two competing 3-D basic types—*wide-screen* and binocular *stereoscopic projection*—which is the more hopeful of survival?

No one can give an answer that is certain as to the outcome. At most, all that can be done is to weigh up the respective merits and demerits of both, with an eye to probable developments and the likely trend of public caprice.

The facts in the matter are soon stated. Wide-screen sets out to provide the unconscious urge we all have, when looking at something, to see it in relation to its accompanying scene elements on either side, dimly perceived out of the ' corner ' of the eyes. ' Stereo ', on the other hand, provides those impressions of depth which we have long been accustomed to dispense with in picture reproductions, but which nevertheless are the normal concomitant of normal real-life vision. Wide-screen pictures must, due to their added width, lose a certain amount of definition and be susceptible to a little more distortion, as compared with a ' straight ' picture. Stereo, whilst losing little if any definition, is inevitably linked with a pronounced and variable distortion in depth, depending upon the viewing distance from the (two-dimensional) screen; at least in its ' natural vision ', ' interocular-interaxial ' mode. Both require more powerful arcs; and stereo, up to the moment, an added projector

On balance so far there is no great disparity in gains, losses and cost. But when we try to assess the audience reaction, whereas stereo alone gives the new thing, a lifelike picture in depth, wide-screen remains the old familiar ' movie ' with the added attraction of extra width; and there is no encumbrance, no *spectacles* to wear.

The necessity of wearing spectacles for viewing stereo is indeed the major argument against it and one that may prove crucial in the long run and tip the scales against its permanent

retention in its present form. On the other hand, a supporting two-dimensional film in a programme featuring a 3-D stereo looks uncommonly flat, and it might be that one could not view with indifference and without nostalgia its final supersession by wide screen.

In this connection it is well to remember that there would appear to be no reason why a marriage of the two modes should not be within measurable sight in the normal course of foreseeable development. Then indeed the combination of peripheral vision and vision in depth would so spectacularly imitate Nature that we might, without protest, take naturally to spectacles.

*

CHAPTER IX

STEREO TELEVISION

THE impetus that the advent of 3-D has given to the prospects of an extra dimension, or at least of a wider horizon, to motion-pictures in the cinema has naturally prompted the question, and undoubtedly stimulated the answering research into possibilities, as to why 3-D techniques should not be applied also to television.

GENERAL CONSIDERATIONS

It should be remarked at once that the real answer to the quest for stereo T.V., almost certainly lies in the discovery of a practical form of the same sort of 3-D that the motion-picture world awaits—an integrating system where the audience perceives the added dimension without glasses and differentiated as between one particular viewing point and another, as in real life. As mentioned earlier, however, there are in the writer's opinion and information no technical developments in sight or within the realms of reasonable conjecture which would allow one to take an optimistic view of a practicable outcome along these lines for a period of time to be measured in decades. In saying this, whilst stressing the analogous features in the two allied problems, the point is being made that this ideal solution of the ciné problem would be also ideal for T.V. in that the optimum presentational requirement is the same, and the technical layout of the electronic and visual circuits is compatible to such a solution. In both cases, however, the basic problem is the major one of *information.* That is to say, in the case of both two-dimensional motion-picture and T.V. screens, present-day technical resources are stretched to the limit in providing an adequate number of units of information in a given time—let us

say very roughly and conservatively, of some 25,000 ' element ' units twenty-four or twenty-five times a second. How are we to multiply this number to give the required additional dimension; for the number of elements then necessary can, as a quick and readily-perceived assessment, be arrived at by *squaring* the existing number—a multiplying factor, upon present definition standards, of 25,000 times! In the motion-picture problem, neither the present type of photographic film emulsions nor the photographic optical train can be conceived of as holding out the possibility of improvements of this order, hard put to it as they would be in showing demonstrable developments in sight of the order of, say, $\times 2$. On the other hand, the analogous problem in T.V. is one primarily of a transmission frequency band-width sufficiently wide to carry the additional information necessary. In most areas of the already highly congested ether, within the allocated ranges of frequency, the problem of finding the $\times 3$ band width for such stations as are to carry *colour* T.V., when it comes, would be a sufficient puzzle in itself. That of finding room for a third dimension is of a different order and would appear to need an entirely different method of approach; unless indeed we are concerned only with two-picture stereo of to-day's type.

Disregarding therefore integral types of T.V. as impracticable within the foreseeable future, it remains to explore the present possibilities where only two pictures, constituting the stereoscopic pair, are involved. There are here, as in motion-picture practise, two types of methods which can be applied: the one using the paraphernalia of existing integrating methods and thus not needing glasses; the other using one or other of the ' viewer aids ', described in Chapter IV.

TWO-PICTURE 'INTEGRAL' T.V.

The methods of viewing T.V. without glasses are soon examined as the possibilities in the light of present knowledge are few.

Grid Methods

First there is the method of the grating or grid. An application of this principle would involve for example the projection,

upon say a translucent screen at the transmitting end, of the left and right pictures constituent of the stereoscopic pair passed through a grid in a similar manner to that described for motion-pictures and in such a way that the vertical strips into which the two pictures have been divided are imaged alternately side by side one after the other across the width of the screen. The resulting grid pattern on the screen is ' viewed ' by the transmitting camera, whether the scanned scene be a live one or that of a televised film. At the receiving end the gridded composite pattern appears on the television tube face in front of which a further grid, appropriately similar to that at the transmitting end, is superimposed at an appropriate small distance. As in the cinema analogue the left-eye picture in these circumstances would be visible only to the left eye and the right-eye picture to the right eye of a viewer situated at an appropriate position in front of the screen. As in the cinema case, however, although some two or three alternative viewing positions might be available side by side in a row at a particular distance in front of the screen, such positions would have between them gaps in which an inadvertent viewer would see the picture pseudoscopically instead of orthoscopically—that is to say, with the depth impressions reversed; near objects being apparently far away and distant ones near. At other distances in front of the tube face, other rows of viewing positions might be found where partially successful results could be observed, but these would be of an inferior type marred by vertical striations. Even in the optimum positions, it would be essential for the audience to keep their positions and to keep their heads still. The results achievable are therefore at best of a not very attractive order and the method prohibits the possibility of ordinary two-dimensional T.V. being viewed at the same time as an alternative, if stereoscopic viewing is not desired, as the gridded pattern would be unresolvable on a gridless tube face. This system of 3-D, T.V. is thus not *compatible* with the simultaneous ' transmission ' simultaneously of a two-dimensional alternative choice, which is doubtless a strong pre-requisite, especially in the transitional stage in passing from an established two-dimensional audience established at the fabulous capital cost-figures involved in the provision of viewing equipment.

'Interlace' Variant

A possible variation on the grating theme may exist in the exploitation of the *interlace.* If, for example, two synchronized cameras were switched so that, within the time period of a single picture frame, one transmitted say the left-eye picture on the scan and the other the right-eye picture on the interlace, no appreciable light loss would occur on transmission. Viewing could be either through a suitable grating or through the medium of synchronized alternately-occluding spectacles of a type to be mentioned shortly. Vertical scanning, however, would have to be adopted implying unfavourable repercussions on the resolution of the viewed image.

Lenticular Methods

An alternative to the simple grid, as in the cinema analogue, lies in the substitution of the lenticular corrugations of a plastic sheet, each element of which acts as a cylindrical lens. By such means the considerable loss of light involved in the use of opaque grid bars is much lessened and the definition is improved in that the whole of each constituent left and right picture can be compressed on to the screen. No improvement in the width of the zones in which orthoscopic stereoscopic viewing can be seen is to be expected unless the ratio of lens-element width to picture-strip width is lessened; which will involve loss of light and once again of definition, unless indeed some 'half-way house' to real integral viewing is to be adopted. For example, if the alternate left- and right-eye strips can each consist of a succession of some half a dozen, say, of slightly different aspects of the viewed scene such as would be seen in real life by a lateral movement of the head, then those laterally elongated elements of the limited panorama thus provided would succeed in eliminating the pseudoscopic positions in viewing, except for a momentary 'flick' similar to that observed in passing from one wide orthoscopic band of positions to the next which can be observed in walking past the familiar stereoscopic still photographs of the Kanolt-Bonnet type, now common in shop-window displays.

'VIEWER-AID' T.V.

On the grounds of not being compatible with a simultaneously viewable two-dimensional presentation and of the considerable deficiencies in the technical development so far of two-picture 'integral' methods, it would be optimistic to anticipate an early success in the application of devices of this type. What then of the possibilities in applying one or other of the viewer aids which can be used in discriminating between the two pictures in stereoscopic motion-pictures?

Polaroid Methods

The first of these to leap to the mind is that of viewing by polarized light. It is obvious, of course, that in T.V. we cannot superimpose upon the screen two pictures polarized at right angles, as the electronic-beam flourescent-tube-face combination is not susceptible to polarization. One of two methods only therefore remains. In one, the two pictures can be thrown on the tube face side by side, for example, so that each can emerge polarized by passing through one or other of two polaroid filters, each of which covers the corresponding front half of the tube. Straightforward viewing by polaroid spectacles would, however, not now suffice, even for small television screens, as the pictures must be laterally merged to avoid divergence of the eyes. The viewing spectacles would therefore have to have an optical constituent to effect this necessary convergence, and the system then hardly differs from a purely 'optical' viewer type; the introduction of the polarizing elements having effected little whilst introducing an unwanted light loss. A method due to R.C.A. and Du Mont, however, which employs two T.V. cameras, radiation channels and receivers, overcomes these difficulties by superimposing the two separately received pictures by the interposition of a semi-reflecting mirror at 45° to each tube face, the latter themselves being lined up in proximity to each other at 90°. Thus to a viewing person in front of the mirror one tube face is seen direct and the other superimposed by reflection upon it. If then the 'output' from each is polarized by appropriate polaroid filters, the viewer wearing polaroid

spectacles would see apparently a single combined picture in stereoscopic relief.

Synchronized Shutter Methods

Passing from possible methods using filters of the polaroid type as the viewing aid to those using the alternating occluding shutter viewing-aid principle, an example under development by 'American Television' may be cited. Two T.V. cameras are used, each of which views the scene alternately through the agency of an electronic switch. Both constituent pictures of the stereoscopic pair are thus televised alternately on to a single receiver which is viewed through a cylindrical viewing device mounted on a stand and operated in synchronism with the camera switch so that each eye of the viewer is occluded when its inappropriate picture is being flashed on the tube face.

Anaglyph Methods

In reviewing further viewer-aid possibilities, those of an anaglyph type must clearly await the development and widespread application of colour T.V. There remain then the adaptation of one form or another of the optical viewer.

Optical Viewing Methods

The simplest system of this type would employ the transmission of the two constituent left- and right-eye pictures by either two T.V. cameras or by one camera using a vertical beam-splitter attachment, to produce the two pictures side by side on the tube face. Merging can be carried out by observation through a normal type of vertically side-by-side optical viewer, either mounted on a stand or in the form of spectacles. The same objections to side-by-side viewing apply just as much in the T.V. version as in that of motion pictures, if a beam-splitter has been employed, in that the resultant merged picture is already narrow horizontally; is narrowed still further by the half-vignette dividing lines thrown on one side of the merged picture; and suffers from the undesirability of the observer having to merge the picture mentally by the same eye motion in the same direction as is relied upon to become aware, by con-

vergence, of the relative position in depth of the frontal plane with respect to the plane of the tube face.

There are several alternatives to a side-by-side disposition of constituent pictures if we are to use optical viewing in conjunction with a split-picture technique. We may either place our two pictures on the screen lying on their sides, adjacent to each

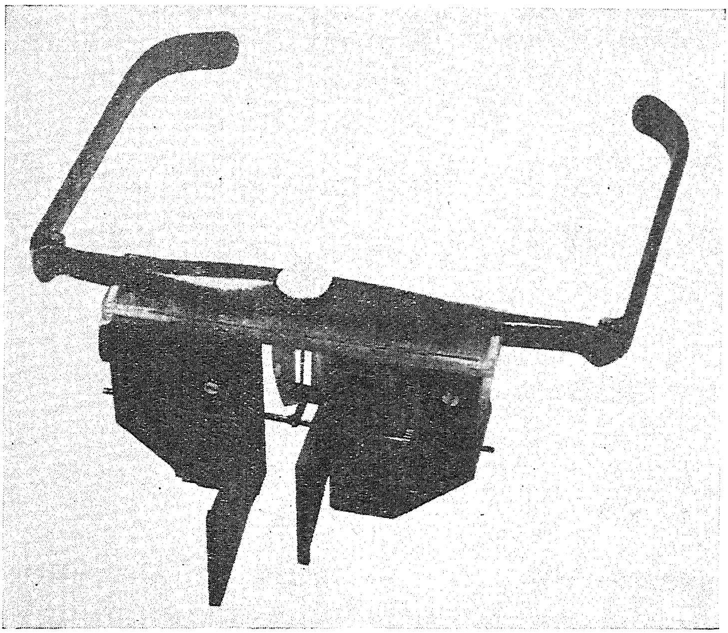

FIG. 55. *Spectacles* for rotating, merging and viewing two head-to-tail projected or televised images when lying on their sides as photographed or 'viewed' with the similar-sense beam-splitting attachment of Fig. 49. (*Crown Copyright photo.*)

other, either head to tail—both to the right or both to the left—or tail-to-tail (or head-to-head) where one is to the right and one to the left. Merging of the latter type by optical viewer means is fundamentally impracticable, unless optics and viewing head can remain fixed—an unacceptable restriction.

The writer has used his 'similar-sense' beam-splitting system mentioned in an earlier chapter to put on the T.V. tube face

the two constituent pictures in a head-to-tail disposition. Viewing is carried out by 'spectacles' in which each eye-piece contains a three-unit reflector system, both in the same sense, to re-rotate the viewed images, and to merge these by a manually controlled movement of one of the reflecting surfaces. A tilt of the head sideways in such a viewing set-up, however, can involve a magnified apparent tilt in the same direction of rota-

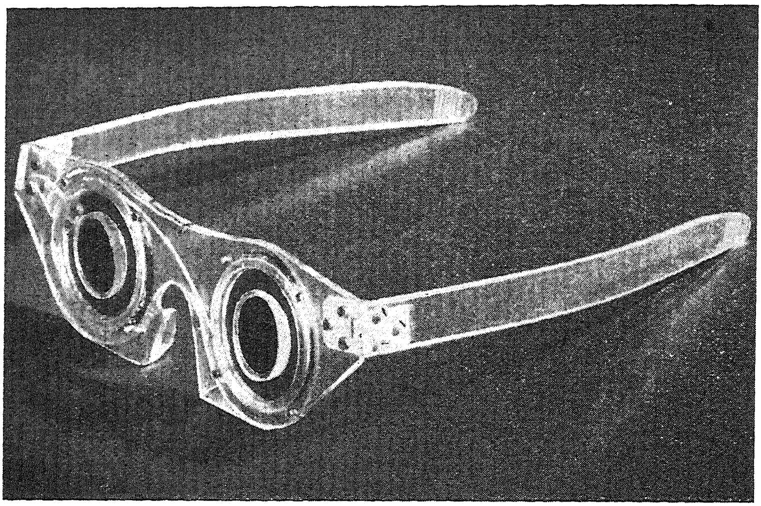

FIG. 56. *Stereo Spectacles (Direct Vision) for T.V.* In addition to the rotating prism wedges the spectacles are fitted with non-rotating polaroid filters on the back for eliminating unwanted images. (*Crown Copyright photo.*)

tion of the viewed combined image. An alternative method of presentation and viewing was therefore developed* in which this function of re-rotation was removed from the viewing spectacles and placed back on the transmitting circuits so that the two head-to-tail pictures were now lying horizontally the right way up, one above the other. Viewing can now be carried out by a choice of simplified forms of spectacles* whereby the merging function is carried out (vertically) by the movement of a constituent part. The convergence function, whereby the brain 'places' the televised frontal plane and the relative

* Patent applications.

position in depth of the contained objects within the reproduced scene, is mentally performed (horizontally) without optical aid in precisely the same subconscious way as that used in real life. Masking of the inappropriate half of the picture pair seen by

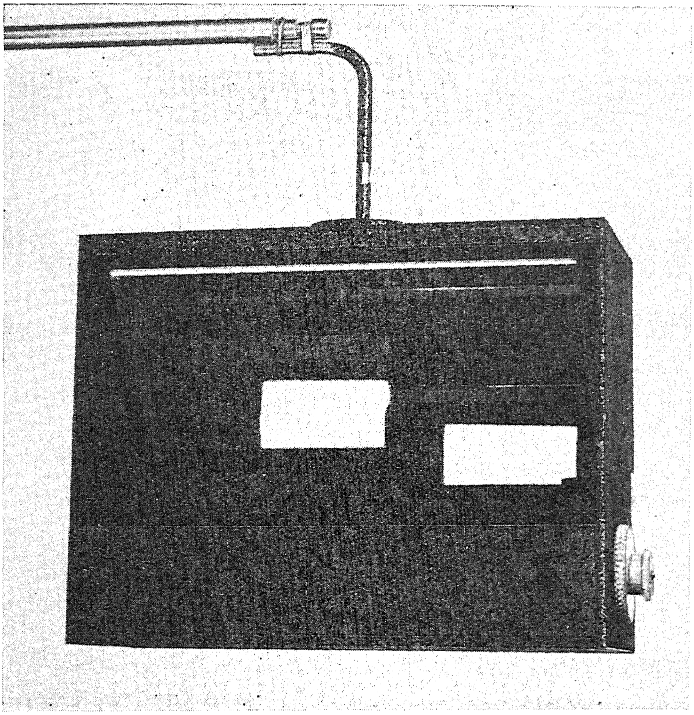

FIG. 57. *Direct-Vision ' Box '* through which, supported in front of the viewer, images projected or televised one above the other can be merged and viewed. The images will have been photographed or ' viewed ' with the similar-sense beam-splitting attachment of Fig. 49 and will have been re-rotated at the projector or T.V. camera. (*Crown Copyright photo.*)

both eyes can be effected by fitting polaroids to the T.V. half tube-faces and the corresponding spectacles eyepieces. Without masking, three pictures would be seen, one above the other. It is only the superimposed halves of each pair in the middle which display stereoscopic relief that are required.

A further feature incorporated in the spectacles utilizes optical

means* for magnifying the viewed stereoscopic picture. This device permits the picture to be seen natural size, the magnification making up for the loss incurred in viewing merged pairs of pictures—each constituent of which is necessarily only roughly a half of the tube-face area—and in so doing the magnification automatically puts the viewing observer virtually at the optimum viewing distance from the tube. This feature, applicable of course in analogous circumstances to the viewing of Stereoscopic Motion Pictures when optical viewing aids are brought into play, removes that major drawback, associated with three-dimensional presentation on two-dimensional screens, of the phenomenon of exaggerated depths observed at distances from the screen exceeding that of the optimum viewing distance.

STEREO T.V. METHODS IN REVIEW

From the sketch given of the possibilities apparent, especially of those that have merited and received development, it is clear that there is at the moment of writing no system replete with all the necessary virtues. Let us rapidly review the methods that have been dealt with in turn.

As in the Motion-Picture field, an emergence of the ideal *integral* type of presentation, dispensing with glasses in viewing, is not in sight. The ‘ half-way house ’ of Two-Picture Integral methods based on *grid* or lenticular screens have severe limitations in the inherent restrictions in the viewing positions relative to the tube face that can be taken up, to say nothing of those technical difficulties involved in ‘ holding ’ a transmitted grid-pattern stationary on the tube face within the tolerances implicit within the necessarily small ‘ pitch ’ of the screen grating appropriate to the normal size of the T.V. tube face. The avoidance of ‘ shot-silk ’ effects, too, are probably very great. In any case two-picture integral methods are non-compatible; this same restriction applying also to the ‘ interlace ’ variant which otherwise, unless viewed by synchronized shutter-occluding spectacles, is open to the same objections which apply to the older grid or lenticular methods.

* Patent applications.

Coming now to the two-picture methods using one or other of the viewing aids at the eyes which are available, let us first look at those of polaroid. Of the two variants mentioned earlier, that of the straightforward application of side-by-side presentation combined with polaroid filters is, in some measure, non-compatible whilst being otherwise unattractive owing to light loss, marginal waste and the viewer's uncertainty as to where the frontal plane should be placed. The second type of viewing with polaroid, using a semi-reflecting mirror, cuts out the uncertainty of frontal plane placing-by-convergence, but is still subject otherwise to the same drawbacks as in the previous variant whilst doubtless being susceptible also to others, such as ghosting, inseparable from the introduction of the mirror.

Methods in which *synchronous* viewing by *alternate* eyes is adopted might be promisingly attractive except for their non-compatible nature. The necessity for electrically or mechanically synchronized drives, presumably involving connecting leads, is a definite drawback; whilst there could be some doubts as to a satisfactory physiological reaction by all viewers, especially in prolonged viewing.

If the early advent of colour T.V. is assumed, methods applying the *anaglyph* principle, whilst being non-compatible, would also be open to similar doubts physiologically. Some considerable light loss is an added drawback, whilst the impossibility of eventually showing stereo T.V. in colour by this method appears to rule it out in spite of its otherwise attractive feature of simplicity.

There remain the *optical* methods of viewing T.V. Whilst being, like those of polaroid viewing, in some measure non-compatible, a considerable drawback exists in the unwanted pictures lying on either side of the merged picture in stereoscopic relief sandwiched in the middle. Although masking can obscure these, such a method is not proof against movements of the viewer's head, inadvertant or otherwise. On the other hand, optical methods suffer no appreciable light loss and are conveniently adaptable to the introduction of magnification and hence the elimination of exaggerated depth effects fundamentally associated with viewing at a distance.

The present outlook for stereoscopic television is, by and

large, not then one of immediate promise and none of the 'interim' methods of achieving it, except possibly this last optical-polaroid method—given adequate development—would appear capable of satisfactorily and acceptably putting a third dimension on the air whilst awaiting the full blossoming of the, as yet, dimly conceived integral ideal.

BIBLIOGRAPHY

1. ALBADA, Gen. Van. A wide-angle stereoscope and a wide-angle viewer, *Trans. Opt. Soc.*, **25**, 1924.
2. BERNIER, R. V. Three-dimensional motion picture applications, *Jour. S.M.P.T.E.*, **56**, 599–612, June 1951.
3. *Bibliography of Stereography.* (400 references.) The Stereo Society, 274 Pearl Street, New York 58, N.Y., U.S.A. ($ 1.50.).
4. BODROSSY, F. *Magyar Technika*, May 1952.
5. BREWSTER, SIR DAVID. *The Stereoscope.* John Murray, London, 1856.
6. COLARDEAU, E. *Traité général de Stéreoscope.* J. de Francia, Paris, 1923.
7. DEWHURST, H. Auto-Precision Stereoscopy, *Phot. J., Sec. B.*, **92B**, 2–24, Jan.–Feb. 1952; Progress in stereoscopic projection, *Journal of Photographic Science*, **1**, 55–60, 1953.
8. DUDLEY, L. Stereoscopy in the Telecinema and in the future. *J. Brit. Kinemat. Soc.*, **18**, 172–181, June 1951.
9. French Patent No. 938,023; BONNET, M., Étude du procédé de relief ' verivision holding ', *Bull. de l'Assoc. Franc. des Ingenieurs et Techniciens du Cinema*, **9**, 11–16, 1951.
10. GILLET, A., CHRETIEN, H., and TEDESCO, J. The panoramic screen projection equipment used at the Palace of Light at the International Exposition (Paris, 1937), *Jour. S.M.P.E.*, **32**, 530–534, May 1939.
11. HILL, A. J. A mathematical and experimental foundation for stereoscopic photography, *Jour. S.M.P.T.E.*, **61**, 461–486, Oct. 1953.
12. IVANOV, S. P. British Patent No. 602,794, Jan. 1941 (accepted June 1948).
13. IVES, H. E. Traill-Taylor Lecture before the Royal Photographic Society, 1933.
14. JUDGE, A. W. *Stereoscopic Photography*, 3rd rev. ed. Chapman & Hall, London, 1950.
15. KAPLAN, S. H. Theory of parallax barriers, *Jour. S.M.P.T.E.*, **59**, 11–21, July 1952.
16. LAND, E. H. Vectographs: images in terms of vectorial inequality and their application in three-dimensional representation, *J. Opt. Soc. Am.*, **30**, June 1940.
17. LAW, H. B. A three-gun shadow mask colour kinescope, *Proc. I.R.E.*, **39**, 1186–1194, Oct. 1951.
18. LAW, R. R. A one-gun shadow mask colour kinescope, *Proc. I.R.E.*, **39**, 1194–1201, Oct. 1951.
19. LUNEBERG, R. K. *Mathematical analysis of binocular vision*, Princeton University Press, 1947; The metric of binocular visual space, *J. Opt. Soc. Am.*, **40**, 627–642, Oct. 1950.

20. McLaren, N. Stereographic animation, *Jour. S.M.P.T.E.*, **57**, 513–520, Dec. 1951.
21. Millet, E. Some geometrical conditions for depth effect in motion-pictures, *Jour. S.M.P.T.E.*, **59**, 517–523, Dec. 1952.
22. Murroughs, T. R. Depth perception with special reference to motion pictures, *Jour. S.M.P.T.E.*, **60**, 656–670, June 1953.
23. Newcomer, H. S. Wide screen photography with cylindrical anamorphosing systems and characteristics of motion picture lenses and images, *Jour. S.M.P.E.*, **20**, 31–53, Jan. 1933.
24. Norling, J. A. Three-dimensional motion pictures, *Jour. S.M.P.E.*, **33**, 612–634, Dec. 1939; Progress in three-dimensional pictures, *Jour. S.M.P.E.*, **37**, 516–524, Nov. 1941; The stereoscopic art—a reprint, *Jour. S.M.P.T.E.*, **60**, 268–308, March 1953.
25. Report on Screen Brightness Committee Theatre Survey, *Jour. S.M.P.T.E.*, **57**, 238–246, Sept. 1951.
26. Rule, J. T. The geometry of stereoscopic projection, *J. Opt. Soc. Am.*, **31**, 325–334, April 1941; The shape of stereoscopic images, *J. Opt. Soc. Am.*, **31**, 124–129, Feb. 1941.
27. Saunders, B. G. Resolution in stereoscopic projection, *Jour. S.M.P.T.E.*, **60**, 651–655, June 1953.
28. Savoye, F. Les procédés de cinema en relief, *Rev. Photographie optique*, Feb. 1951; Vision directe, *Rev. photographie optique*, Dec. 1950.
29. Segaller, D. The Russian stereoscopic cinema, *Discovery*, 355–358, 361, Nov. 1949.
30. Spottiswoode, R. Progress in three-dimensional films at the Festival of Britain, *Jour. S.M.P.T.E.*, **58**, 291–303, April 1952; and with Spottiswoode, N., and Smith, C., Basic principles of the three-dimensional film, *Jour. S.M.P.T.E.*, **59**, 249–286, Oct. 1952; and with Spottiswoode, N., *The theory of Stereoscopic Transmission*, University of California Press, 1953.
31. Southall, J. P. C. *Helmholtz's Treatise on Physiological Optics.* The Optical Society of America, 1925.
32. Vanet, P. La prise de vue et la projection en relief en vision collective directe, *Rev. photographie optique*, March 1951.
33. Wright, W. D. The role of convergence in stereoscopic vision, *Proc. Phys. Soc., Section B.*, **64**, 289–297, April 1951.

INDEX